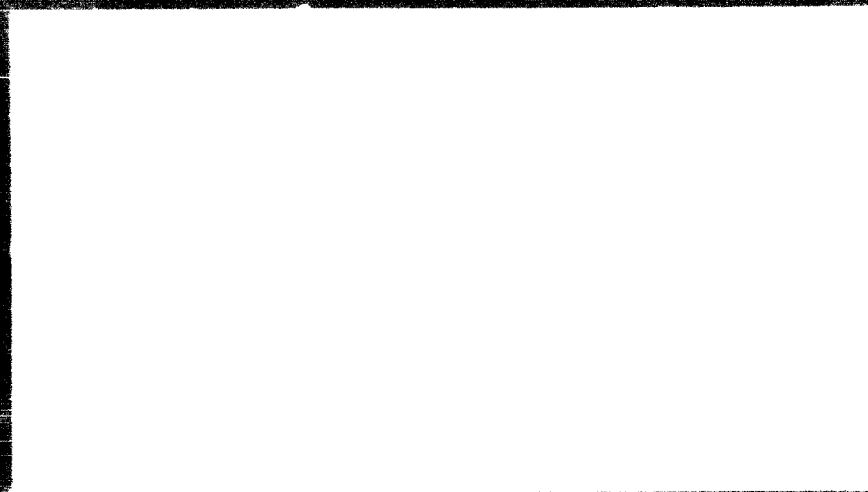


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NASA/UNIVERSITY
ADVANCED MISSIONS SPACE DESIGN PROGRAM

LUNAR SANDBAG TRANSPORT SYSTEM

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LAUNCHER

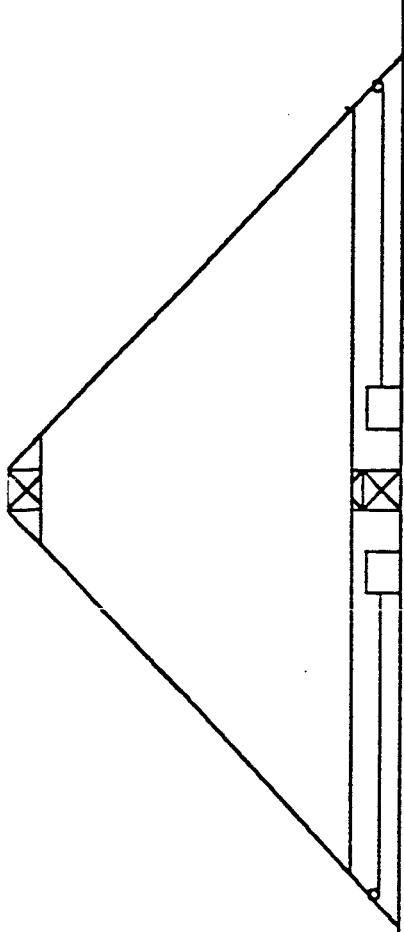
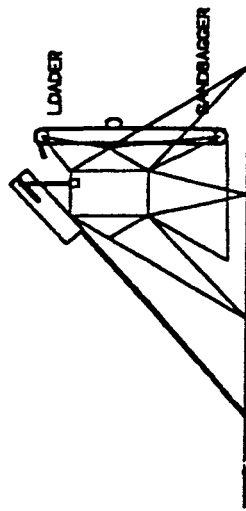


ILLUSTRATION OF DESIGN PROJECT

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I. Abstract:

The lunar sandbag transport system presented in this report involves a catapulting and catching mode of transportation through space. Such a mode of transportation takes advantage of the lack of any atmosphere on the Moon and the fact that the Moon's gravitational force is one-sixth that of Earth. The system must consist of three basic operational steps. These three steps are loading, launching, and catching the sandbag.

The loading step of the system operation must be designed to be completely compatible with the operation of the lunar sandbagger. At the time of this report, insufficient information was available on the lunar sandbagger to design a complete loading operational step. However, this report does recommend a method that would work quite well with further consideration.

The launching step of the system operation uses mechanical compression springs to store a large amount of energy and then apply this energy to the sandbag over a short launch distance. The exit velocity of the sandbag from the launcher is detected and controlled by velocity indicators and electric motor braking forces, respectively. By varying this exit velocity and launching each bag at a 45 degree angle, the target location can be carefully controlled.

At the target location the catching step of the system operation is utilized. The catching system absorbs the energy of the sandbag, thus stopping the bag, by using a tough material stretched across a support structure. The ends of this material are attached to cables which are wound around spools. Upon impact, the sandbag forces this material to be stretched, thus unwinding the cables from the spools. The spools are damped by motors which operate as generators, and therefore the energy of the sandbag is somewhat recovered by turning the kinetic energy of the sandbag to electrical energy when the bag impacts and unwinds the cables from the spools. The motors then wind up the cables into a taught position.

The lunar sandbag transport system presented in this report meets the performance objectives and design constraints of the problem statement. Again, by taking advantage of the unique lunar environmental conditions, this mode of transportation has many advantages over conventional modes used on Earth.

II. PROBLEM STATEMENT:

A. Introduction:

The current design for a lunar base calls for cylindrical modules to be partially buried in the lunar soil and then insulated from heat and radiation by a covering of lunar soil. This soil could be loosely piled, formed into bricks, or collected into sandbags. Because of the tremendous energy cost of excavating into the hard lunar surface, only the loose topsoil would be collected and bagged (assuming sandbags are used for insulation). This would necessitate going some distance from the modules to collect soil. Therefore the distance the bags would have to be transported from where they are made to the modules could be quite large.

Since the Moon has essentially no atmosphere and only one-sixth of the Earth's gravity, throwing and catching the sandbags could prove to be an efficient mode of transportation. Assuming sandbags are used to insulate the modules and throwing is used for transportation, the design problem is to determine the type of throwing and catching system that would be best for use on the moon.

B. Performance Objectives:

The launcher/catcher system will be designed to meet the following performance objectives:

1. Operating Parameters:

- a. **Throwing Distance:** The launcher should operate at a radial distance from five modules that will provide sufficient sand volume to cover the module surfaces with sandbags. This distance is approximately 300 meters.

- b. Sandbag Weight: The launcher will be required to launch a sandbag which will be approximately 100 kilograms each time.
- c. Rate of Launching: An efficient rate will be determined based upon the final design. It must be fast enough to make this concept of sandbag transportation a better choice than alternative concepts. The proposed rate will be one bag per minute.
- d. Reliability: Due to its location and accessibility, the system should work well for a large number of repeated cycles without major maintenance. The system must complete a continued process, not a one repetition process.
- e. Launch Positions: Since the launcher/catcher will be mounted on the lunar walker, the system must be able to operate from a number of positions.

2. Completely Automated:

Due to the limited accessibility of the Moon, and the difficulty of working in its environment, the launcher/catcher system should be completely automated. The system should be automated in terms of the following two parameters:

- a. Weight: The launcher/catcher must automatically weigh each sandbag to be launched in order to determine other launch parameters.
- b. Distance: The system must be able to adjust to different target locations automatically.

C. Constraints:

The following constraints on the design of the launcher/catcher system must be considered:

- 1. Weight: The approximate cost to transport material and equipment from Earth to the Moon is estimated to be well over \$20,000 per pound. This

high cost of transportation puts important limitations on the design of the system from a weight standpoint. The need to keep the launcher/catcher system lightweight must be adhered to during all phases of the design process.

2. Environment: The environment on the surface of the Moon is much different than that of Earth. Some of the important environmental conditions which will limit the design of the system are as follows:
 - a. There is effectively no atmosphere , and therefore a vacuum exists.
 - b. The temperature ranges from approximately 200 degrees Fahrenheit to -200 degrees Fahrenheit.
 - c. There is considerable solar radiation
 - d. Incoming meteor showers often hit the lunar surface.
3. Transport and Placement on the Moon: The launcher itself must be designed such that it can be mounted and transported to each location by a lunar walker which has been previously designed.
4. Energy Sources: The energy sources available for use on the Moon are limited. The energy requirements of both the launcher and the catcher systems must be designed around sources which are feasible and available.

III. SYSTEM DESCRIPTION AND ANALYSIS:

A. Loading Operation:

Obviously a method to obtain the sandbags after they are filled with sand by the sandbagger and load these bags into the launcher is an important process in transporting the bags. Many different methods were considered to perform this operation. However, no final decision could be made as to what system will be used. In order to finalize such a decision, close communication between the designer's of the sandbagger and launcher is required, because the two systems will be operating in conjunction with one another. As the two systems are further developed and improved, the best method to interface these two systems will become evident.

At this point of development of both the sandbagger and the launcher, there is one loading method which looks promising. This loading method takes advantage of the fact that the sandbagger will be mounted on the underside of the lunar walker, and the launcher will be mounted on the top of the lunar walker. In this configuration, the loading system would involve a conveyer type system. A chain drive could be used to vertically lift the sandbags from the sandbagger. Hooks on the chain links could be designed to grab the bags. These hooks will extend out from the chain and would grab the handle provided on the sandbag and lift the sandbag to the launcher. The hooks will be opened and closed through the use of cams. The system would be fixed, and the launcher will move to a fixed position for each loading. A preliminary drawing of this loading system is provided in Appendix A.

B. Launching Operation:

Description Of Mechanism:

Overall Configuration: The overall configuration of the sandbag launcher is similar to that of an

artillery gun. It is cylindrical in shape, it is inclined at an angle, and it launches sandbags along a linear launch path. The overall configuration of the launcher, including important dimensions, is provided in Appendix A. The launcher mechanism consists of the following parts:

(Note: Details of each of these parts are provided in Appendix A.)

Bag Holder Assembly: The bag holder assembly consists of a cylindrical bucket into which each sandbag is placed for launch. This bucket is sized to accommodate a two cubic foot sandbag which will weigh approximately 100 kg. Extending out from this bucket radially in seven equidistant directions are arms which connect the sandbag bucket to seven launch guidance rods. Each of these seven launch guidance rods extend along the length of the linear launch path and are used to transfer the launch force from the launch springs to the sandbag bucket. This whole assembly; bucket, arms, and guidance rods, is one complete piece.

Springs: The power required for launching the sandbags will be provided by seven large compression springs. These springs have a free length of 3.2 meters, a solid height of 1.0 meter, a wire diameter of 17 millimeters, and 59 turns at a diameter of 18 centimeters. This all allows a compression distance for launch power storage of 2.0 meters.

Spring Housings: To eliminate buckling of the compression springs, each spring is housed in a cylindrical tube. The tubes extend approximately 300 degrees around the spring allowing a space for the connecting arms to move linearly with the bag holder. The housings extend over the entire length of each spring and are also used as support structures for the launcher.

Load Washers: Each spring is capped on both sides by a load washer. This load washer transfers the spring force to the guidance arms through shoulders on the guidance rods and therefor to the

launch bucket. These washers move along the inside of the spring housings and are fitted with linear bearings on their inside diameter and outside diameter to provide smooth linear movement.

Support Rings: Connecting each of the seven housings at three equidistant locations from top to bottom are support rings. These support rings maintain the shape of the launcher and are used in support of the launcher. The bottom support is fitted with a flat plate on which the motor and spool for cocking the launcher are placed.

Motor, Spool, and Cable: A D.C. motor is mounted to the base plate. The motor has a spool mounted to the shaft where a steel cable is wound. The other end of the cable extends to the bottom of the launching bucket and is attached to a ring there. The motor winds the spool to pull the bucket down.

Launcher Cover: The outside of the entire launcher is fitted with a mylar reflective cover to reflect radiation from the sun and thus keep the launcher from being heated beyond acceptable temperature limits.

Performance:

The maximum performance characteristics of the launcher were developed by considering the working environment and requirements of the NASA space modules. These parameters were maximum throwing distance, bag velocity, cycle time and acceleration.

Environment:

The lunar atmosphere is basically a vacuum. This means the bags would not lose any initial kinetic energy to friction or air resistance over the course of the flight from launcher to catcher. Therefore, the situation is ideal and lends itself to the ideal projectile motion equations of physics for determining performance parameters.

Parameters:

Throwing Distance:

The maximum distance the launcher must throw a sandbag is used to calculate the other parameters. However, the distance itself is first determined from NASA data. Each module needs a 2 foot thick covering of sandbags. The sand is collected from the top three inches of the lunar surface. Therefore, to have enough sand to fill enough bags to cover the projected five modules, the sand must be collected from as far as 300 meters radially from the modules. Therefore, the launcher must be able to throw bags up to a distance of 300 meters. An alternative plan calls for three consecutive throws, each of 100 meters, or two throws, each of 150 meters, to make up the 300 meter distance. However, this launcher design delivers enough power for the entire 300 meter distance in one throw.

Bag Velocity:

The velocity necessary to throw the bag 300 meters was calculated using the following equation:

$$V = ((x * g) / \sin(2\theta))^{1/2}$$

$$\begin{aligned} \text{where } g &= 1.635 \text{ m/s} \\ \theta &= 45 \text{ degrees} \end{aligned}$$

As the equation shows, the launch angle is 45 degrees for maximum distance. Since the calculation is for a maximum distance, this is also a maximum velocity. A program with various velocities for varying distances is in appendix B.

Acceleration:

The acceleration necessary to bring the bag from rest to 22 m/s, maximum velocity for

300 meters, was calculated using the following equation and varying the distance, R, which would be the acceleration distance of the launcher.

$$a = V^2/2 \cdot R \quad \text{where } R = \begin{array}{l} \text{acceleration} \\ \text{distance} \end{array}$$

The results are again in the computer program in appendix B. However, after designing the springs for the launcher, an optimum distance of 2 meters was chosen, with a corresponding acceleration of 122.5 m/s^2 .

Cycle Time:

The cycle time has three parts, the wind down time, release time, and damping time. Release time is the time it will take for the bag at rest to reach maximum velocity of 22 m/s by accelerating at the calculated 122.5 m/s^2 . This is based on the following equation:

$$\text{Time} = (2R/a)^{1/2}$$

This results in a time of 0.1807 seconds for release. After consulting the sandbagger group, it was determined that the bagger will operate at an optimum frequency of 1 bag per minute. Therefore, 1 minute per cycle was selected as an optimum cycle time. This leaves over 58 seconds for loading, winding and damping. With such a long time available for winding the springs, less power will be required. Winding time is the largest portion of the cycle time.

Launch Power System:

Initial analysis of the problem to be solved provided the exit velocity for the sandbag in order to launch it 300 meters at a 45 degree launch angle. In

addition, the approximate mass of the sandbag was known. From this information, the energy needed to be supplied by the launching mechanism was calculated as follows:

$$\begin{aligned}\text{Total Energy} &= \text{Kinetic Energy} + \text{Potential Energy} \\ &= 1/2 (\text{launch mass})(\text{exit velocity}) \\ &\quad + (\text{launch mass})(\text{lunar gravity}) \\ &\quad (\text{height})\end{aligned}$$

Where: launch mass = bag mass + bag holder mass
 = 130 kg
 exit velocity = 22.136 m/s
 lunar gravity = 1.635 m/s²
 height = cos(45 degrees)x2 meters

From this equation it can be found that the total energy required to be delivered by the system is approximately 32150 Joules. Of course, this energy requirement does not include energy losses due to friction, but friction losses will be very small and compensated for by controls.

The largest problem encountered was deciding what mechanism would best deliver the amount of energy necessary to launch the sandbag in the fraction of a second acceleration time required. Given the energy availability constraints on the moon, the ability to build up and store energy in a system which can later deliver the entire energy supply in a very short time is essential. Many different systems which can provide this ability were considered. Such systems include; charging a capacitor, building up voltage in an inductor, and storing energy in mechanical springs.

The most efficient method to store energy and supply it later is by electrical means as mentioned above. However, a launch mechanism which can be used to deliver the energy to the sandbag must be compatible to the energy storage method. Many launch mechanisms which can be powered by electrical means were considered. Only one method fit the needs and constraints involved in this particular project. This method is the linear induction motor. Such motors have

been used successfully in transportation devices such as monorails and high speed trains. Research is continuing in the application of these motors as aircraft catapults aboard aircraft carriers. The advantages of a linear induction motor are that it is lightweight, predictable, and reliable. If research continues, this could be an excellent method for catapulting the sandbags in the future. However, currently no experience base is available to accurately size and select a linear induction motor for our purposes. The sources that were consulted all suggested that the design of a system at this point would be beyond the time frame of this course because the linear induction motor is still being researched.

Therefore, the storage of energy in mechanical springs became very attractive. Using this method, the energy required for launch can be stored in the same mechanism which will deliver the energy to the sandbag. In addition, because of the linear relationship of force to displacement inherent in a spring, the analysis is greatly simplified.

Many types of mechanical spring mechanisms were considered, including: torsion springs, fluid springs, leaf springs, compression springs, and extension springs. Further in depth analysis of each of these mechanisms showed that the simplest and therefore best method to store and supply the launch energy is either extension or compression springs. In fact, a combination of the two springs is very attractive due to the ability to damp out the motion of the bag holder after launch. However, there are inherent problems with each type of spring. Extension and compression springs used under high forces and stresses can be deformed and stretched out of shape. Compression springs can buckle when the deflection to length ratio becomes too large. Therefore, the use of buckling preventive housings becomes very attractive. This arrangement allows the use of compression springs without the concern of buckling. In addition, the spring can be used as an extension spring after launch in order to damp out the motion remaining in the bag holder.

Finally, it is noted that springs used in parallel have the advantage that the spring constants are additive. Therefore, the use of many springs attached

to the bag holder produce the same resultant force as one very large spring, which by itself might be too large and be overstressed.

Following the considerations and decisions mentioned previously, the group came up with the design of a launch mechanism which is made up of seven compression springs, each separated by a housing. The seven springs surround the bag holder in a complete circle. The force produced by the seven springs when they are cocked before launch is transferred to the bag holder via load washers and guidance rods which extend through each spring. The details, as described earlier, are provided in the drawings of Appendix A.

Arriving at the optimal spring size and number which would fit the needs of this design was an important consideration. The springs need to be the lowest total mass possible, provide the necessary total spring constant, have a reasonable wire diameter, length, and coil diameter, and not be overstressed. In order to design the spring arrangement, a computer program was written to find the optimal number and size of the springs. This program and an example of some of the output is provided in Appendix B with the important calculations shown.

Controls and Operation:

Pre-launch controls:

Sensors:

Since the launcher will be located at various distances of up to 300 meters from the catcher, it is necessary for automatic sensors to determine critical parameters for an accurate launch. It is first assumed there are no obstructions between the catcher and the launcher to obscure the line of sight. The group chose to use a laser rangefinder on the launcher for determining range and for aiming the launch tube. Advantages are its small size, accuracy,

light weight, reliability, low power consumption, and can be easily interfaced with a microprocessor or an on board computer. A wide variety are currently in use in surveying and military targeting. Promising designs, patents, and products, are available from companies such as RCA, Lockheed Engineering and Management Services Company, Martin Marietta Corporation, and Kollsman Instrument Company.

The size of a typical laser rangefinder is about 45 centimeters long. It can be expected to weigh roughly 3 kilograms. Energy consumed is approximately 10 millijoules and is derived from our fuel cell system.

To facilitate detection, the top of the catcher mast will have a reflective coating in accordance with the laser wavelength (typically 1.06 microns).

For operation, the lunar walker should first position itself so that the launcher is generally facing the catcher (+ or - 20 degrees). The rangefinder will be mounted such that the on board computer can use 2 small motors to move it automatically or by remote control on a 2 axis system. The rangefinder would start from a standard position. As the catcher is pinpointed, the on board computer keeps track of relative movements. Then other actuators will be used to aim the launcher accurately.

Range data along with mass sensor data will be relayed to the launch control program in order to preposition the spring system to achieve the correct exit velocity.

Limitations to consider are accuracy and temperature ranges. Current accuracies are about + or - 10 meters, but this can be improved upon. Normal shortcomings can be avoided such as beam scattering and absorption since the moon lacks an atmosphere.

A typical temperature range is from -65 degrees to +140 degrees Fahrenheit. Since the lunar surface ranges from -200 to +200 degrees Fahrenheit, one compensating technique might be to cover the rangefinder with a partially reflective shroud. When the launcher is shaded, heat may be generated internally. It can also be derived by having the rangefinder in contact with any of the actuating motors which dissipate heat while in operation.

In case of a malfunction, indicators would alert the on board computer. Malfunction indicators are typically built into today's rangefinders. A video camera system might also be coupled with the laser to help identify unexpected events and circumstances. This option is also available on many rangefinders.

Actuators:

It is assumed that eight rotary incremental actuators will be used for launcher movements. If the launcher is on a slope, it will be leveled with two lead screws and their actuators. The platform will rotate 360 degrees for aiming. A rod will be positioned to contact the lunar surface in order to help absorb launch forces. Two small actuators will direct the rangefinder. Sand bags must be put into the launch tube. Extending the spring system for launch is the largest application of actuators. The computer will control all movements. A gear train is used to increase speed where necessary.

The rotary incremental actuators chosen are brushless DC motors manufactured by Schaeffer Magnetics of Chatsworth, California. A broad family of actuators are available and have been used extensively on many previous space missions. These motors have been used on the Pioneer II telescope

drives (1970), an antenna positioner (1977), the scan mirror on Dynamics Explorer, the TDRSS gimbal drive assembly, and many aspects of the Space Telescope such as the solar array panels and secondary mirror positioning.

The motors are highly reliable and have built-in redundancy. For several types of actuators, a failure has never occurred in orbit. Published data specifies a step of .0075 degrees and a rotation rate of 2.2 degrees per second. For rotating the launcher to aim at the catcher 300 meters away, this gives a horizontal step of less than 4 centimeters. Tests show maximum error to be no greater than 3 centimeters from the desired position. Motors weigh from 1/2 to 5 kilograms each. An attractive characteristic is unpowered holding torque (11.3 Nm minimum, 62.2 Nm maximum). Operating torques are about 56 Nm minimum, and operating speed is .039 radians per second for the larger models.

Pre-loading:

Once the computer has calculated the required exit velocity, it computes the distance the spring must be compressed to deliver this velocity. This calculation assumes the spring to be linear, so an additional increment is added to insure the required velocity is attained (the velocity is more precisely regulated during the launch phase). The position of the motor is sensed and multiplied by the spool radius and the voltage is varied to wind the spring down to the desired position. Because at full compression the spring generates 27,200 Newtons of force, it would require a motor capable of 2.6 kW of instantaneous power to wind the spring at a constant velocity in the 50 second cycle time. This would have to be a custom designed brushless system. Once wound, the spring is held by a catch and the motor turned off.

Velocity Control:

The velocity is controlled by a feedback loop that uses the DC motor to apply a retarding force to the spring bucket assembly (see Appendix B). This insures an exact exit velocity. If all the system parameters are correct, one can determine the armature voltage required and the gain needed to provide a peak overshoot that corresponds to the desired exit velocity within a certain range of error, in this case, 1%. Once the bucket reaches peak velocity and begins to slow down, the sandbag continues at the peak velocity and leaves the system.

Stopping Control:

In order to prevent major damage to the assembly and reduce the cycle time, the bucket needs to be arrested soon after launch. The feedback loop is the same as for velocity control except that the mass is now decreased. Desired velocity is now zero. Once the spring is stopped, the positioning cycle begins again.

Structure And Support:

The launcher will be mounted on the top side of the lunar walker. Part of this mounting structure will consist of launch adjustment mechanisms which provide two degrees of freedom for the launcher separate from the walker itself. The rotating angular adjustment parallel to the lunar surface will be provided by a turntable arrangement. The turntable will be set inside a large roller bearing which will itself be mounted on the walker. The launcher will be mounted onto the

turntable. The turntable is basically a mounting plate with gear teeth. The launch angle will be adjusted with power screws attached to the turntable arrangement. The motion for each of these adjustment mechanisms will be provided by DC motors. Brushless stepper motors will be used because this type of motor will be reliable in the hard lunar vacuum.

The instantaneous forces created at launch exceed the maximum load that can be sustained by the lunar walker. Therefore there are two possible means to provide support for the launcher during launch:

- 1) Build a separate, sturdier lunar walker.
- 2) Build additional support for the launcher.

The best solution to this problem is to build an additional "leg" extending from the launcher along the line of action of the launch force. This leg is essentially a tubular support truss which must withstand axial forces. The leg will be extended down to the lunar surface for each launch.

The entire mounting and support structure is shown in detail in the drawings provided in Appendix A.

Materials:

The most important consideration in selecting the materials for the launcher is the fact that each of our seven springs will be used to produce a great deal of force and will be used under high stress conditions. For these reasons, a material for the springs with a high modulus of rigidity as well as a material which can withstand a relatively high stress is required. Careful examination of various materials often used for spring applications revealed one material which meets the specific needs of the project. Chromium-vanadium spring steel wire is a good quality alloy steel containing small amounts of chromium and vanadium to increase the hardness, tensile strength, and endurance properties of the material. It is a popular spring material for applications involving higher stresses

than can be used with high carbon spring steels and for springs which will be under impact or shock loads. It can be used in relatively high temperature applications, up to 425 degrees Fahrenheit, which is a desirable characteristic for the application described in this report. The important properties of the chromium-vanadium spring steel are as follows:

Commercial Specification: ASTM A 231
Modulus of Elasticity: 203400 MPa
Modulus of Rigidity: 77200 MPa
Density: 7.85 grams/cubic centimeter
Maximum Recommended Design Stress: 485 MPa

The second most important consideration in selecting materials for the launcher is the high cost of transporting equipment to the Moon on a mass basis. For this reason low density materials are very desirable. This objective had to be compromised somewhat in choosing the spring material for the important reasons mentioned above. However, the remainder of the launch mechanism required the use of high strength rigid materials. In these applications, the low density material objectives can be satisfied.

The sandbag holder, the extending arms, and the attached guiding rods are designed to be made of Kevlar. This composite material has excellent mechanical properties combined with a very low density. In addition to these parts, the seven spring housings will also be made of Kevlar. The important mechanical properties of the Kevlar composite are as follows:

Modulus of Elasticity: 124020 Mpa
Tensile Strength: 3617 Mpa
Density: 1.44 grams/ cubic centimeter

The load washers used in the launch mechanism will be made of a strong high carbon steel which can withstand large compression loads. The launch mechanism supports will be made of an aluminum alloy material which is both lightweight and strong. In addition, the support leg which withstands the axial force of the launch will be made of an aluminum alloy material.

A third important consideration in choosing materials for the launching mechanism is heat transfer. The vacuum conditions of the lunar environment make convective heat transfer non-existent. Therefore the only way to heat the launch system beyond reasonable temperature limits is to produce heat within the system or to allow radiation from the sun to heat up the system's outside surfaces and conduct the heat through the system. In addition, the only way to cool the system below reasonable temperature limits is to allow the system to radiate heat into space. The internal heat generation problem will not present a problem in itself because the cycle time of the system is only one cycle per minute and thus enough heat to affect the system's performance won't be generated. However, to alleviate the radiation problems, a cover for the launcher was chosen. This cover will be made of a low thermal conductivity mylar material coated with a reflective surface finish on the outside surface.

Energy Systems:

Many alternatives are available for supplying electrical energy to the launcher, including solar, batteries, nuclear and fuel cells. Solar was eliminated due to the 2 week solar night, in which no sunlight is available. Nuclear was eliminated due to its size and weight. Batteries do not have a long life. Fuel cells have been used successfully on previous space missions. Their advantages are light weight, low volume, long life, and the by product of a hydrogen-oxygen fuel cell is environmentally clean water. Fuel cells are also a more efficient electrical conversion device than other current alternatives. Therefore, fuel cells were chosen as the energy system.

The specific requirements for the fuel cell for this project are a maximum power of 3 kW delivered over one minute cycles. The life must be long enough to provide at least as many cycles as the number of bags necessary to cover 5 modules. Every fuel cell is uniquely designed for a specific purpose; therefore, specific size and weight for this cell is not available.

Failure Modes:

The two basic sources of failure in the launcher are failure due to the environment, and failure of the mechanical components.

Environment:

Environmental failures are caused by the lunar environment's effect on material properties. These aspects of the lunar environment are thermal stresses due to the broad temperature range (-200 to 200 F), the vacuum type atmosphere, solar radiation, and meteor showers.

Meteor Showers:

If the launcher were struck directly by a meteor it would become inoperable. However, a design that withstood a meteor strike would be weight prohibitive. Prior lunar landings have neglected this event due to its low probability of occurrence. That assumption will hold for this project also.

Radiation:

Since there is no atmosphere, more of the sun's radiation reaches the lunar surface than the earth's surface. To protect the launcher, a mylar reflective cloth will shield the launcher, as used on previous space projects.

Vacuum:

With no atmosphere, there is no atmospheric pressure. This allows all fluids and lubricants to escape and evaporate unless securely sealed. Several lubricant films have been used successfully in the lunar environment. Furthermore, with no atmosphere, convective heat dissipation is not available. This may be handled by using a large area of material to allow radiative heat transfer.

Thermal Stresses:

Due to the extreme temperature differential between lunar day and lunar night, several problems may occur in the launcher. The metals will become brittle at the extreme low temperature. The spring stiffness will not remain constant, thus interfering with throwing distance, and the motor may overheat. To overcome these problems, materials with low temperature sensitivity were selected. Also, the mylar shield will help to maintain a constant operating temperature by reflecting the heat extreme and trapping internally generated heat during the cold extreme. Finally, it is recommended that the initial start-up of the launcher be at a temperature of 32 F or warmer.

Component Failure:

Springs:

The seven springs are the most important component for storing energy in the launcher. They may fail by fatigue, by excessive shear or tensile strengths or by buckling. In addition, for the amount of energy needed, a very large stiffness, K , is required.

Buckling will not occur since each spring is encased in a support housing. As for the K value, springs in parallel are additive. Therefore, with an optimization program (see appendix B), 6.86 springs were found to be able to supply the necessary energy, with reasonable K values for each spring. The project uses 7 springs, which overcompensates for the high K value.

Excessive stresses are handled by material selection. Using chromium-vanadium springs allowed design stresses higher than calculated values.

Finally, the springs must be able to work many cycles repeatedly and have a long life. Calculations were made that indicate a life of 5000 cycles, which is more bags than are necessary to cover the five modules.

Bag Holder and Support Arms:

The critical parts of this component are the small connecting arms between the bag support and each of the seven springs. This is also where the most stress will be applied, since that is where the force of the springs is transferred to the bag. High strength Kevlar was selected for these parts. Kevlar has an ultimate tensile strength of 3617 Mpa, which is greater than any stresses due to the motor and cable. Failure of these parts due to creep and plastic deformation is covered, since the operating temperature is held nearly constant.

Washers:

The washers are constantly sliding against two surfaces, the outside of the guidance rods and the inside of the spring housing. At high velocities friction could result, causing heat, slowing the launch, and causing long range failure. This has been accounted for by the use of special lubricant films on the sliding surfaces, as well as antifriction linear bearings on the washer.

Motor:

Failure of the motor may occur due to overheating, since large amounts of heat will be generated and the convective heat transfer is negligible in the lunar vacuum. Two solutions will handle this problem. One solution is the mylar shield around the launcher. This will prevent extreme heat from reaching the motor. The other solution for the heat transfer is to use radiative heat transfer by dissipating the heat throughout the launcher structure.

Cable:

Failure may be caused by the motor to bucket cable snapping or getting tangled. Snapping of the cable would occur if the tensile stress on the cable exceeded its yield strength. A high strength cable with a design tensile strength greater than the actual tensile strength is used. The possibility of the cable becoming tangled upon release of the bucket will be controlled by the damping motor.

C. CATCHING OPERATION:

General Description

Catcher

The sandbag catcher is basically a solid fabric net (tightly woven) connected to corrosion resistant aircraft steel cables with electric motor-generators connected to one end of the cable to damp out the motion of the sandbag. The design proposal is similar to an aircraft arresting system utilized at many airports.

The catcher is shaped like a pyramid and therefore multi-directional. Each of the four corners is supported by a cable which is mounted to the catcher structure at the apex. Each cable runs from the apex to the corner of the pyramid where it is attached to a pulley and then directed back towards the center of the pyramid where it is attached to a damping motor-generator. Attached to the cable is the fabric net which spans the entire circumference of the pyramid. Detail drawings of the catcher are provided in Appendix A.

Description of structure

The support structure for the catcher will be made of several components. These are the tower,

cables, outriggers, and braces. Each of these components has a different function and must be designed accordingly.

The tower is the major support for the fabric nets which are used to catch the sandbags. The tower is a space truss with cubical elements. Each of these cubical elements is supported by hollow members along each edge and face diagonal. The height of the tower is 15.35 meters whereas each side of the square tower base is 1.535 meters. The catcher will be centered around the tower with the catching nets attached along the four edges at the top of the tower.

Another component of the catching structure is the outriggers. The outriggers are used as lateral support for the tower and consist of hollow members which run out from the corners of the base of the tower. Each of the four outriggers is 21.71 meters in length.

The cables are also used as lateral support for the tower. They run from the four corners at the top of the tower to the ends of the outriggers at the base of the tower. They are attached to the ends of the outriggers and are 26.59 meters in length.

The braces are hollow members which connect the outriggers at their ends. There are four braces and they form a square at the base of the catcher. Each brace is 32.24 meters in length. The purpose of the braces is to support the outriggers in the horizontal plane.

These four components work together to provide support for the catcher.

Analysis of Catcher:

All calculations used in the analysis of the catcher are provided in Appendix B.

Performance Parameters (Design Characteristics)

The design parameters of the catcher were to catch the sandbag from any direction up to a radius of 300 meters. The catcher was designed for an error of 2% of the flight distance vertically and 1% of the flight distance horizontally. In other words, the area of the solid fabric net was designed to catch the sandbag within these tolerances. The objective of the catcher was to catch the sandbag without damaging the bag or the catcher. The catcher was designed to be stationary thus allowing it to catch the sandbag from any direction.

Keeping the basic design parameters in mind, several subordinate parameters existed. Size and weight were to be minimized, life was to be maximized, power to arrest the bags was to be minimized and the cycle time was to be reasonable enough to allow the design to be feasible.

Sizing of Structural Members

To determine the size of each of the various components necessary to prevent failure by any means, we must first determine the factors affecting failure.

First, the worst possible loading condition for each component is determined. This worst case is then analyzed and a material is selected which can best handle the loading condition. It is noted that the following analysis was performed under the assumption that the anchors for the catcher absorb no force of the sandbag.

Tower:

It was determined that hollow aluminum members would be the best thing to use to build the tower. The reason for this is mainly the strength to weight ratio of aluminum.

The next step in determining the worst case is when the sandbag hits the tower without hitting the nets first. The worst place for the bag to hit the tower is at the corner of the tower and in the plane of one of the sides. For this case, the force of the sandbag is absorbed by five members. A point force analysis was done on the corner to determine the force in each member assuming all members are equally loaded. From this analysis it was determined that the tower members should have an outside diameter of 0.0574 meters and a wall thickness of 0.0144 meters using a safety factor of 2.

Structural Cables:

The cables will be made of solid steel rope because of the high elasticity needed.

The worst loading condition occurs when the sandbag strikes the top of the tower perpendicular to one of the outer members on the top face of the truss. This will produce the maximum bending moment on the tower which is what the cables must be designed to withstand. The case mentioned above was analyzed by treating the tower as a free body and summing the forces and the moments on the tower necessary for equilibrium. Through this analysis it was determined that the diameter of the steel rope necessary to prevent failure was 0.01315 meters. The above analysis was performed using a safety factor of 2.

Braces:

The braces will consist of aluminum members. The worst case of loading on the braces occurs when the sandbag is traveling directly along one of the braces and hits near one of the corners where the cables are connected to the outriggers. For this case, the horizontal force of the incoming sandbag

will be absorbed by one brace and one outrigger. Performing a force analysis on the corner where the sandbag hits, an outside diameter for the braces was determined to be 0.241 meters.

Outriggers:

The outriggers will also be hollow aluminum members. The worst case for loading occurs when the sandbag is traveling directly along one of the corners where the cables are connected to the outriggers. For this case, the force of the sandbag will be absorbed by one outrigger and two braces. Performing a force analysis on the corner where the sandbag hits yields an outside diameter of 0.182 meters for the outriggers.

Braces and outriggers of the sizes mentioned will result in a very large total mass of the catcher. As mentioned previously, the analysis was performed assuming the anchors absorb no force. Under actual conditions, the size and weight of these braces and outriggers may be greatly reduced and possibly eliminated.

Construction of Structure:

The catcher structure consists of a number of members, each of which was designed using a worst case analysis. To ensure that the overall structure does not fail, we must construct the structure so that it will not fail at the connection joints.

In constructing the catcher support, a combination of welding and bolting together of the members will be used. Welding will be used to fasten almost all of the tower members together. To allow for the tower to be broken into two pieces, bolts will be used to connect the fifth and sixth sections of the tower. This will be done by having two sets of members at the common cross section rather than one shared set of members. The

two sets of members will be bolted together to form the tower. All pieces of the tower will be bolted together except for the tower members which will be welded together. It will be necessary to make braces and outriggers out of two pieces which can be bolted together on the lunar surface. Overall the structure needs to be sturdy and compact. A combination of welding and bolting will ensure a sturdy structure.

Anchoring of Structure to Lunar Surface:

The catcher will have a tendency to move around on the lunar surface when impacted by a sandbag. To prevent the catcher from doing this, it will be necessary to anchor it in some way. Since the catcher can be impacted upon from any direction, there is not much need to move it.

The best way to anchor the catcher would be some type of spike which could be driven through the ends of the outriggers to keep the catcher from moving. The size and dimension of the spikes will depend on the depth required for a good anchor. These dimensions remain undetermined.

Power Systems:

The power to arrest the sandbags will be supplied by electric motor-generators. The motor-generators will minimize heat buildup and allow the solid fabric net to be rewound with a minimum amount of parts and therefore weight. They will also allow for part of the energy of the sandbag to be recovered for later use.

The motor-generators will be able to arrest the bag without regard to where on the structure the bag impacts. The reason is because of the control system of the catcher (mentioned later in control section). The bag is to be arrested in a distance that is appropriate so that no damage will occur to the structure. The distance required to stop the sand bag will vary accordingly to where on the catcher the sandbag impacts. The maximum force exerted on the motor-generators will occur only if the bag impacts directly on one

cable. If the bag impacts elsewhere on the catcher, the arresting force will be carried by two motors. The specifications of the four motor-generators are that they be DC permanent magnet motors which are brushless and have a rectifier. They also should be rated at about 10 hp. Again the calculations are done with a factor of safety of 2.

Controls:

The control system of the catcher will deal with only the motor-generators during the damping of the sandbag and the rewinding of the solid fabric net. The catcher need only to catch the bag and expel it a small distance without bursting the sandbag. This does not require great precision so an independent feedback loop is not necessary. It suffices to have tension meters on the cable so that a microprocessor senses the initial tension of impact. At this point the computer calculates the position and speed of the bag and calculates the deceleration profile required. During the first part of the deceleration, the cable drives the motor-generators to make them act as generators. The electricity is then stored to be used in other phases. The energy can be stored during part of the phase until the computer determines its needs to stop the sandbag. It then applies the estimated voltage to the DC motor-generator that retard and then rewind the steel cables. The desired rewinding profile is also calculated from the initial impact so that the fabric net is rewound fast enough to eject the sandbag away from the catcher. These calculated deceleration and ejection profiles may not be exact, but the catcher system can tolerate a fair amount of error. Once the sandbag is ejected, the computer monitors the cable tension and regulates the DC motor-generator to return the fabric net to the initial tension. At that point a catch mechanism engages to hold the cables until a sandbag strikes and the catch cycle begins again .

Materials:

Fabric Net

The fabric net is a bi-level plain woven fabric consisting of a woven teflon. The two yarns are polyester and teflon. The surface will contain the teflon for abrasion resistance, while the strength of the cloth will be carried by the polyester. The polyester is Dupont type 68 commonly used in the military and industry. The teflon is a reflective bleached teflon used in the Apollo missions and the space shuttle. The characteristics of this fabric is that it is very abrasion resistant, strong, and is temperature resistant up to 400 degrees Fahrenheit. The Denier of both yarns should be 1000 gms/9km. This will result in both types having 28 yarns/inch. The resulting strength of each yarn will be 564 lbs/in. The numbers are calculated using a factor of safety of 3. The weight of the fabric will be 28.3 gms/sq. yard. The total area for the fabric net will be 912 m².

Cables and Pulleys

The 4 cables consist of wire rope of the type 7x7 aircraft corrosion resistant steel that is .003175 meters (1/8 inch) in diameter. The strength is 124 kpsi. Each cable should be 50 meters in length. The cables are attached to the apex and are directed to the corners of the pyramid where they are attached around a pulley and directed towards the braking motor-generator. The pulleys should be .0508 meters (2 inches) in diameter and coated with powdered graphite for lubrication. The cable is wrapped around a .1016 meter (4 inch) diameter spool drum which is attached to the shaft of the motor-generator.

Connection of Fabric Net to Steel Cables:

The fabric net is connected to each cable by the way of aluminum snap hooks. The fabric is fitted with brass eyelets .01270 meters, (1/2 inch), in diameter containing the high strength steel snap hooks every .152 meters (6 inches) on the two sides of the fabric triangle measuring 26.6 meters. The cables are fitted with aluminum clamp on plates with .01270 meter (1/2 inch) diameter holes on each side. The aluminum plates start at 3 meters from the apex and are spaced every .152 meters (6 inches) until they are 3.1 meters from the corner. There will be a total of 140 hooks and plates per cable for a total of 560 of each for the entire pyramid.

Energy Supply:

The catcher's motor-generators will be supplied by the lunar module's power supply. They should be fairly energy efficient since they will store some of the incoming energy for later use.

Operation:

The operation of the catcher is rather simple. The sandbag will strike the fabric net and displace it a distance x. The displacement will cause a force on the cables which will be compensated for by the electric motor-generators. The fabric net will be displaced no more than a maximum of 2.5 meters, and therefore the structure will be free from collision. When the sandbag and fabric net come to rest, the motor-generator will rewind the cables at a rate fast enough to displace the bag and draw the fabric net tight. The net will be 2 meters vertically off of the lunar surface in order to allow room for the sand bags to accumulate. This will allow the catcher to operate for a relative long period of time before the sandbags will have to be hauled away.

The catcher will not have to be moved because of its multi-directional capability. This feature will save time and energy. Finally and most importantly, the catcher will be able to catch a sandbag every 60 seconds.

Failure:

The potential areas of failure in the catcher are numerous. Here we will address each and our solution.

The sandbag could strike the top of the aluminum structure causing large stresses and shears, thus failure. Such an event is not anticipated because of the controller on the launcher and the errors taken into account when designing the catcher. However, if the bag did impact against the top of the structure, the structure could probably sustain the impact if the bag were to burst. Therefore a sharp object on the apex of the structure to tear the sandbag upon impact with the structure thus reducing the risk of the structure failure, is recommended.

Another possible area of failure is that of the motor-generators overheating. This may be a problem but the cycle time is adequate enough to allow the motor-generator to cool down.

The fabric net could become snagged or have a sandbag caught in it. This is likely not to happen because the fabric net is tightly woven and is stretched tight enough to prevent either of the above to happen.

These above statements are the major problems that could be fatal to the catcher. There are other problems that could arise but would not be detrimental to the catcher in terms of operation.

IV. VOLUME AND MASS SUMMARY:

The calculations used to determine the following volume and mass summary are provided in Appendix A.

A. Launcher:

Shipping Volume of Launcher = 2.0 cubic meters

Mass of Launcher:

Springs = 417 kg
Bagholder assembly = 30 kg
Spring Housings = 146 kg
Supports = 1 kg
Washers = 2 kg
Axial force rod = 14 kg
Launch controls = 75 kg
Walker interface = 100 kg

Total Launcher Mass = 785 kg

B. Catcher:

Shipping Volume of Catcher = 45 cubic meters

Mass of Catcher:

Fabric = 30 kg
Hooks and plates = 91 kg
Tower = 1840 kg
Cables = 114 kg
Braces = 11910 kg (see note below)
Outriggers = 4575 kg (see note below)

Total Mass of Catcher = 18560 kg
(see note)

C. Total mass of System = 19345 kg (see note)

Note: The mass of the catcher structural members is too large considering the weight constraints of this project. A solution to this problem is discussed in the report and recommendations.

V. CONCLUSIONS:

The design group is quite satisfied with the sandbag transport system presented in this report. Not only does the design satisfy all of the performance objectives and constraints placed upon the design, it also offers a high level of efficiency.

The design group incorporated three efficient features into the design. First, by using springs for the launching mechanisms, we have minimized the instantaneous power supply requirements, thus allowing the use of a small fuel cell. Second, the group designed the catcher to be multi-directional, therefore eliminating the time and energy required to move a unidirectional catcher. Third, an important feature is the ability of the motor/generator dampers of the catcher to retrieve some of the energy used to launch the sandbags. The accuracy of this system is ensured by various computer control systems on both the launcher and the catcher.

Because of a lack of specific information regarding the sandbagger system, the group was unable to design the mechanism for loading the sandbags into the launcher. We did consider two possible methods for this system. These methods are the use of a robot arm and the use of a conveyer system.

The design group, as mentioned above, is quite satisfied with the progress made on the design of this lunar sandbag transport system. The design basically started from scratch. The result is, what the group believes to be, a versatile and feasible solution to the problem of transporting sandbags in the lunar environment.

VI. RECOMMENDATIONS:

This project was an initial design of a new idea. The design is not finalized, because improvements in certain areas are possible. The following areas are recommended for further investigation:

- 1) Investigate the use of linear induction motors/rail guns instead of springs for the launching mechanism. Applications of these units so far have been limited and research is continuing.
- 2) Investigate using some type of expandable folding structure for the catcher.
- 3) Integrate the sandbagger design to facilitate a more efficient system design. This would include a system for loading the launcher directly from the sandbagger.
- 4) Optimize the number of sides of the catcher with respect to weight and directional freedom for incoming sandbags.
- 5) Further optimize the motor/generators used on the catcher system to provide a better energy return.
- 6) Re-analyze the catcher braces and outriggers, taking into account the forces absorbed by the anchors, in order to reduce or eliminate their large mass.

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COMPANIES:

Catcher:

All American Engineering Co.
Newark, Delaware

Motors:

Reliance Electric
Cleveland, Ohio
Dale May
Roger Daugherty
Howard Jordan
Jerry Gareson

Springs:

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Springfield, Ohio

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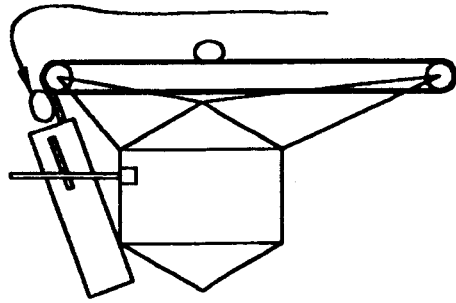
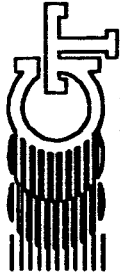
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LIST OF APPENDICES

Appendix A:	Design Drawings
Appendix B:	Calculations and Computer Programs
Appendix C:	Design Decisions
Appendix D:	Design Alternatives
Appendix E:	Weekly Progress Reports
Appendix F:	Patent Disclosure

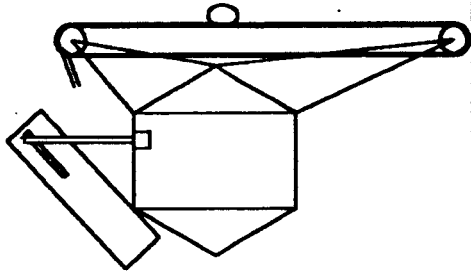
APPENDIX A
DESIGN DRAWINGS

LUNAR SANDBAG DELIVERY SYSTEM



SANDBAGGER

LOADING MODE

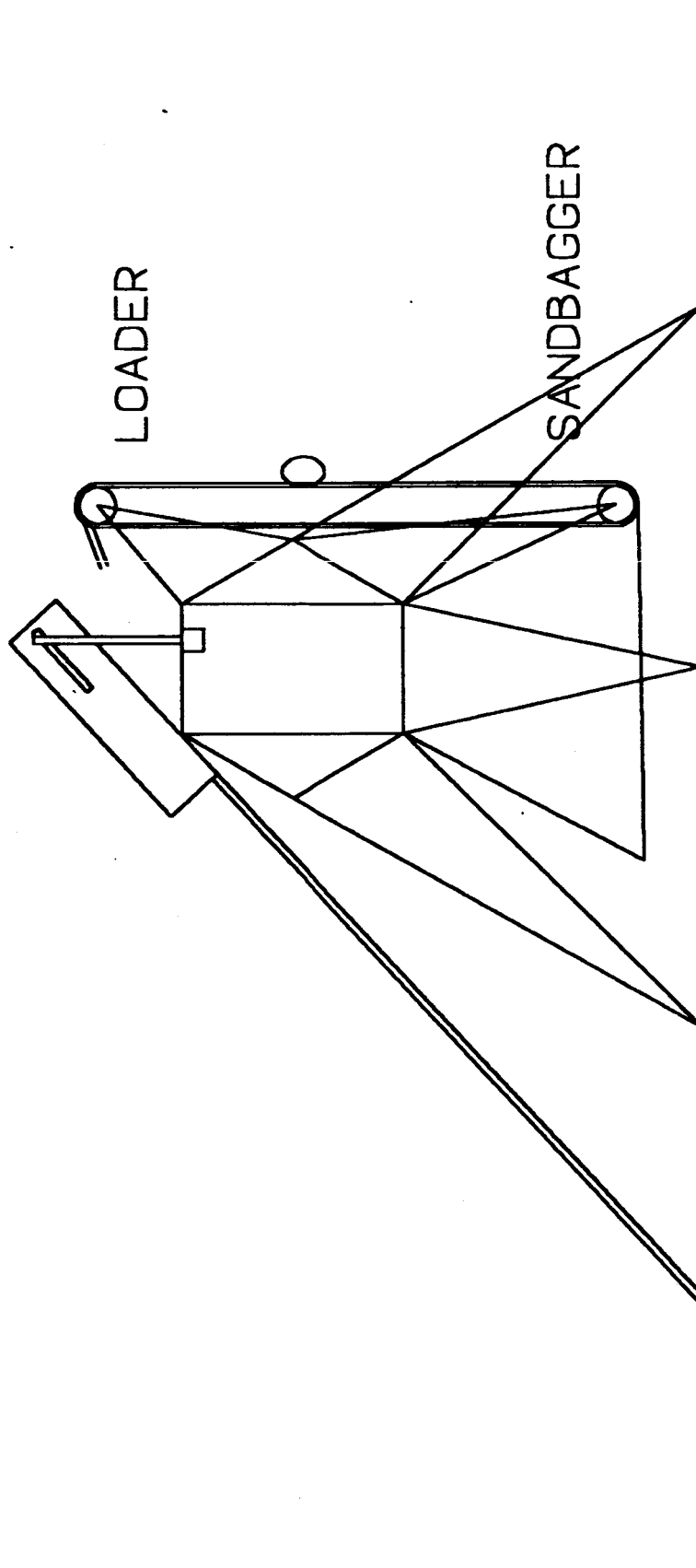


SANDBAGGER

LAUNCH MODE

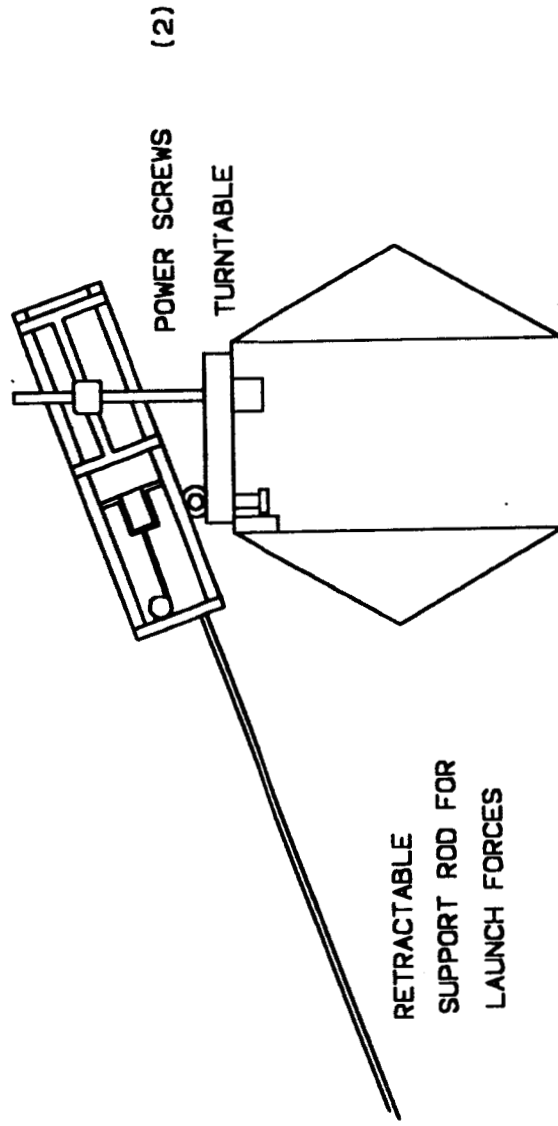
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LAUNCHER





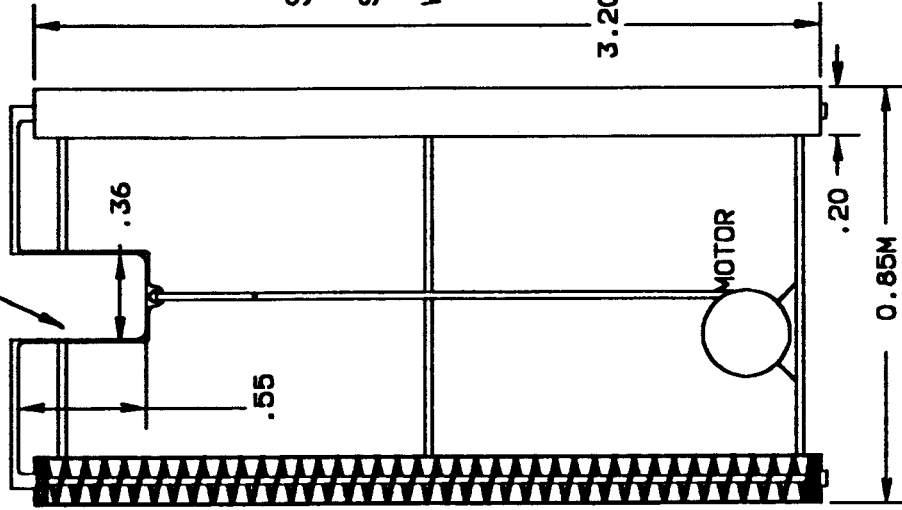
LUNAR LAUNCHER SIDE VIEW WITH WALKER BODY



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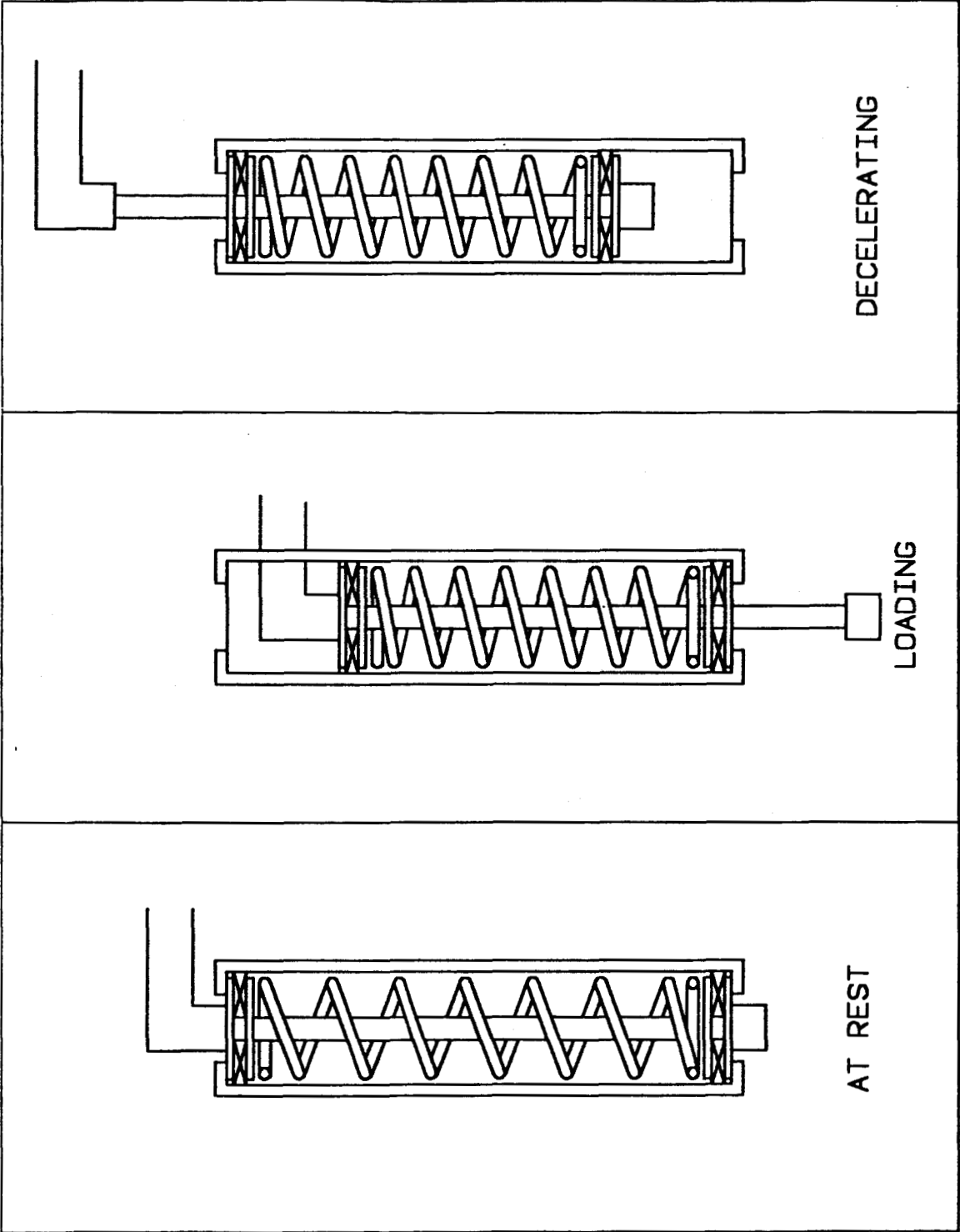


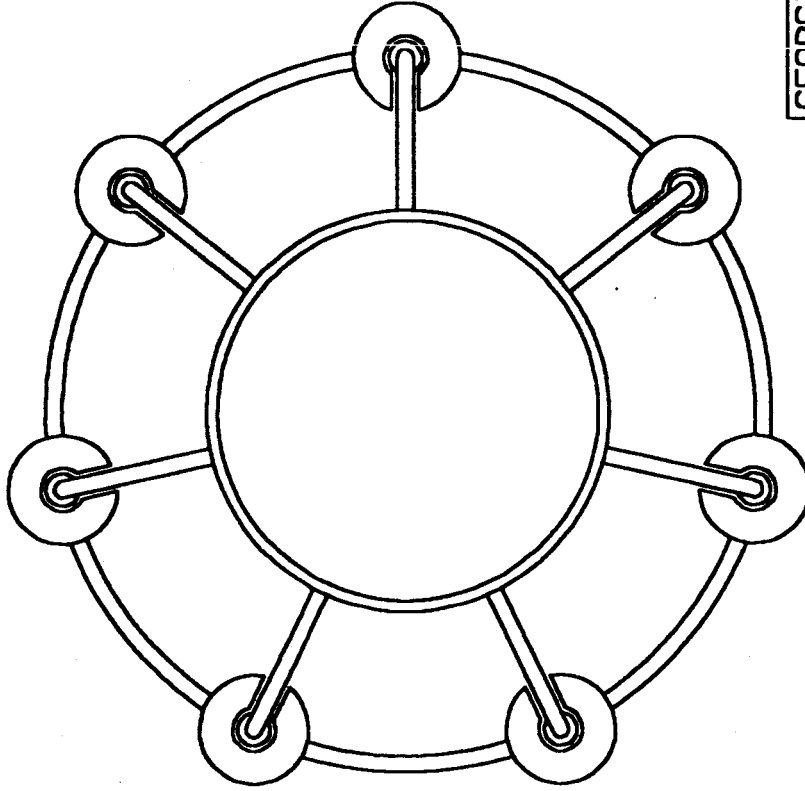
SANDBAG HOLDER



SIDE VIEW
SEVEN SPRINGS
WOUND BY BRUSHLESS MOTORS

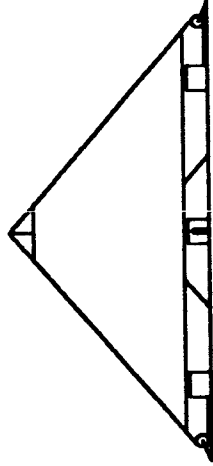
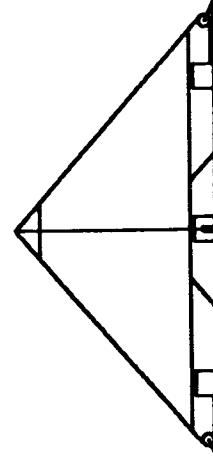
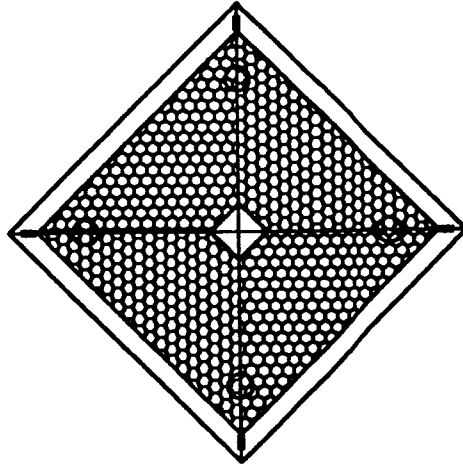
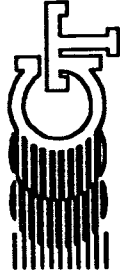
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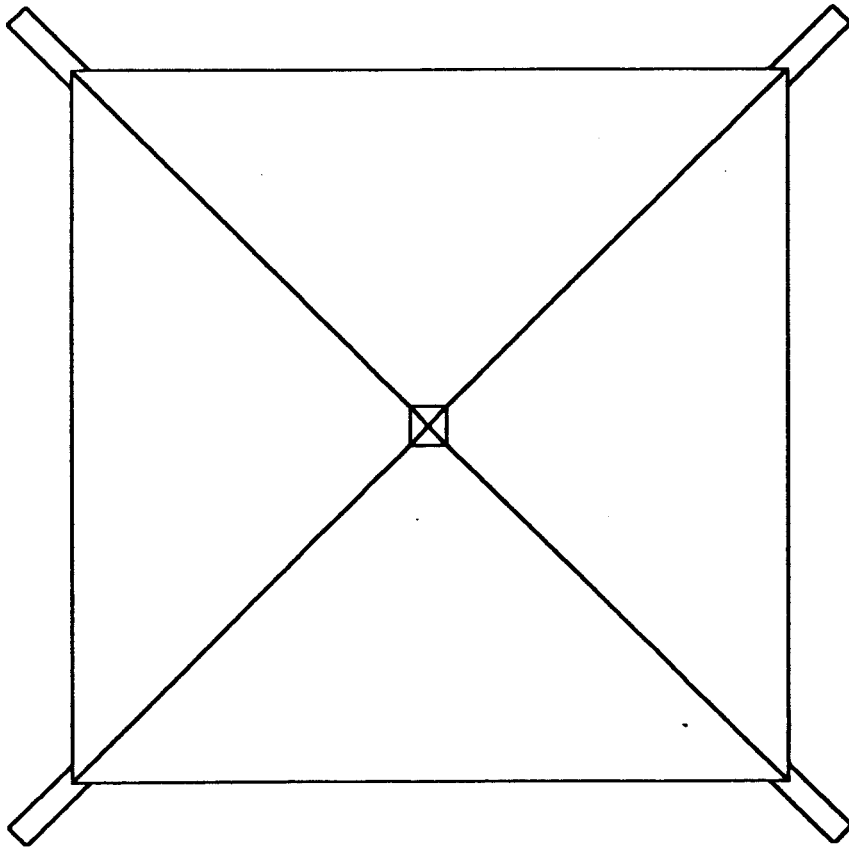
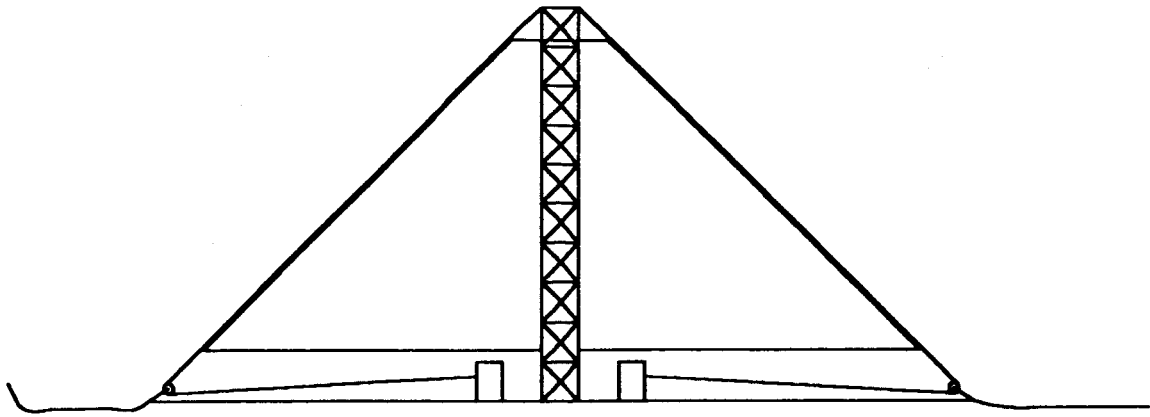


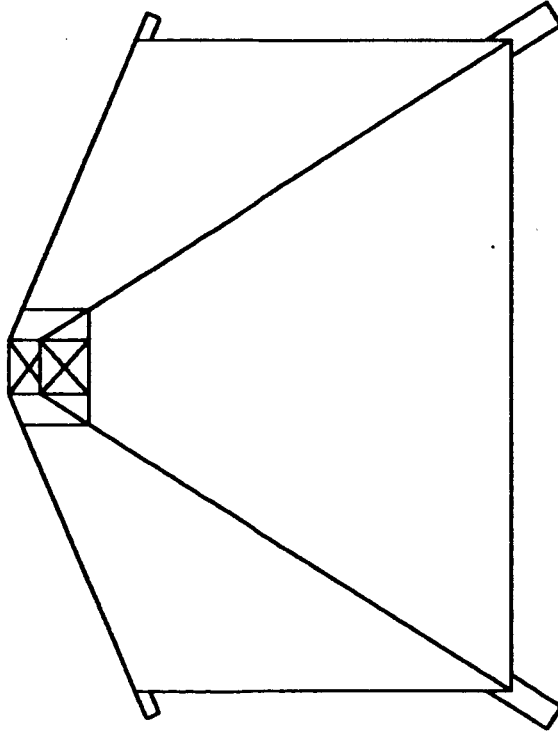
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MULTI-DIRECTIONAL SANDBAG DECELERATOR



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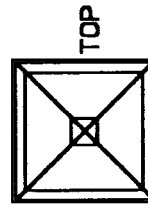
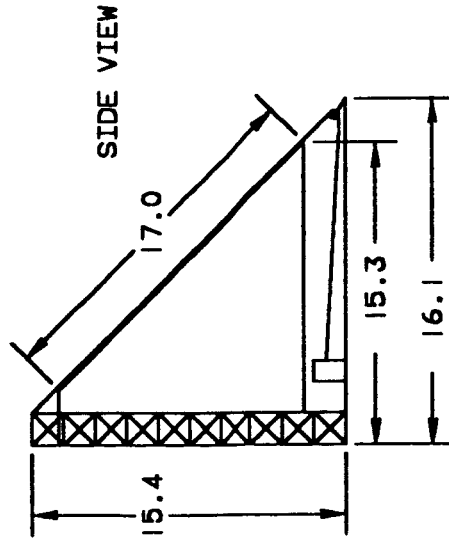
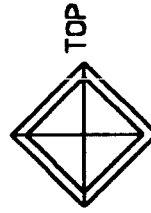
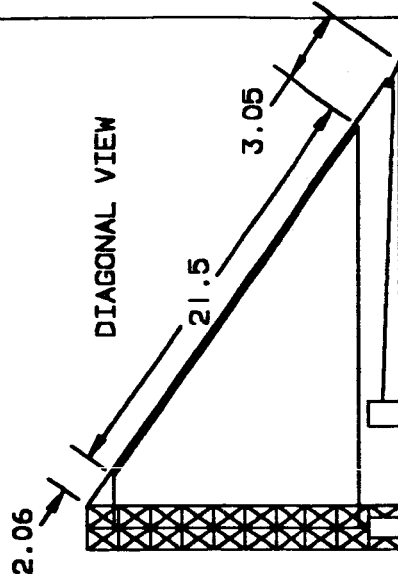
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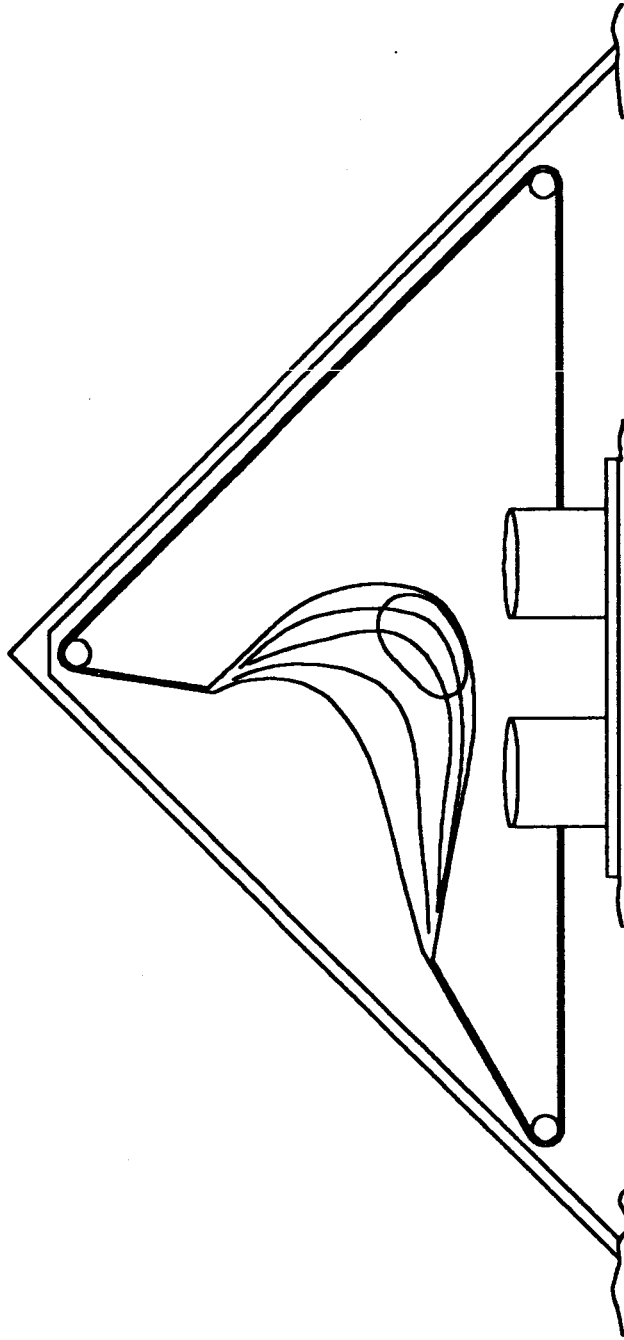
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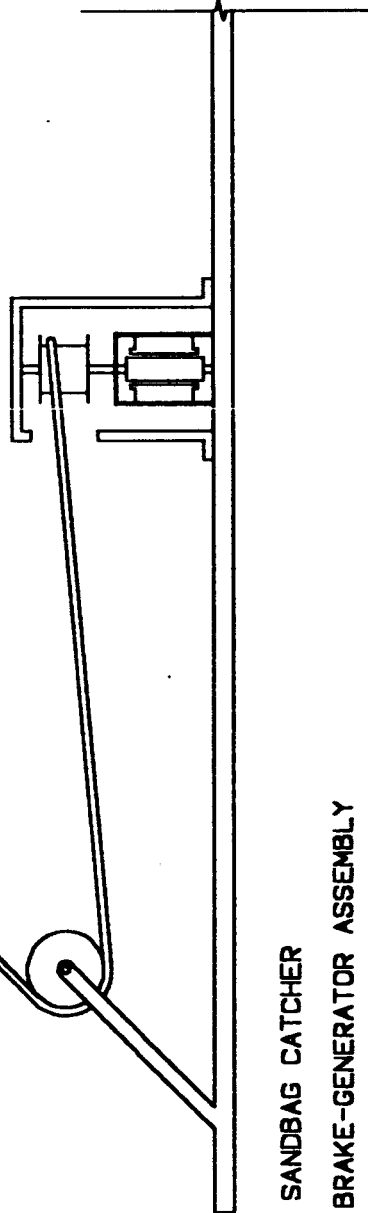


TO TOP OF TOWER

1/8" AIRCRAFT
CABLE

SIDE VIEW

CUTAWAY VIEW OF MOTOR



SANDBAG CATCHER
BRAKE-GENERATOR ASSEMBLY

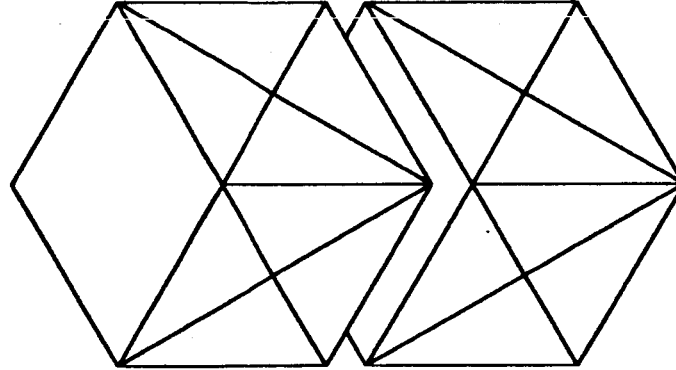
GEORGIA TECH
COLLEGE OF ENGINEERING

TITLE: LUNAR LAUNCHER

DESIGN ME4182.2 DATE 6/1/87



TYPICAL TRUSS BLOCK



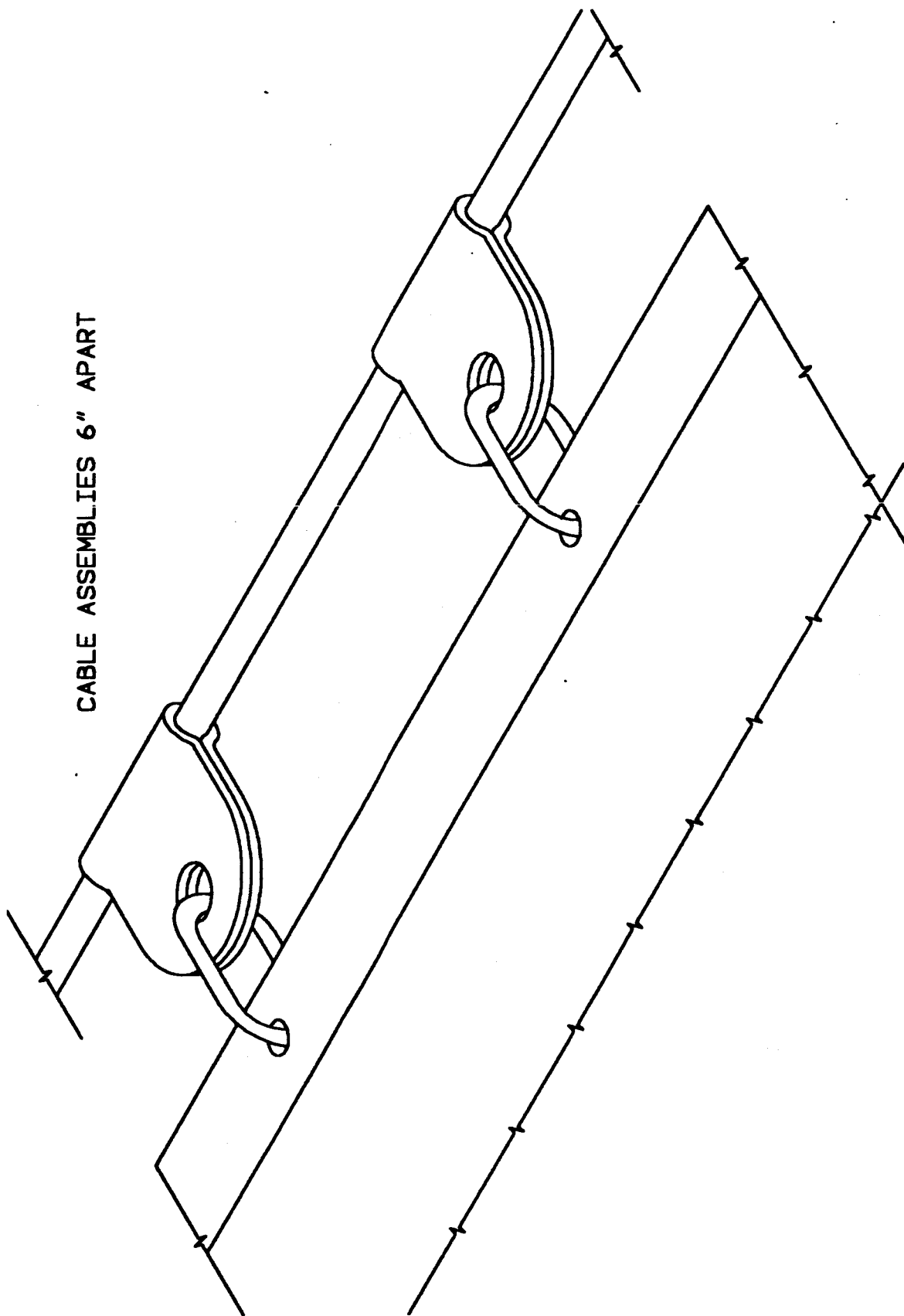
ALL SIDES 1.54 METERS

DIAGONAL MEMBERS
ON SIDE FACES

STRUCTURE BUILT
10 CUBES HIGH

GEORGIA TECH
COLLEGE OF ENGINEERING
TITLE: LUNAR LAUNCHER
DESIGN #E4182.2 DATE 6/1/87

CABLE ASSEMBLIES 6" APART



APPENDIX B
CALCULATIONS AND COMPUTER PROGRAMS

LAUNCHER CALCULATIONS:

Calculations

Distance = 300 meters

Acceleration of gravity (A) = $\frac{9.8}{6}$ meters/second²

Mass of sandbag (m) = 100 kg

Angle of launch (θ) = 45°

Distance of acceleration (R) = 2 meters

Required Parameters

Velocity

$$V = \sqrt{\frac{x \times A}{\sin 2\theta}} = \sqrt{\frac{300 \times \frac{9.8}{6}}{\sin 90^\circ}} = 22.136 \text{ m/sec}$$

Time

$$T = \frac{2V \sin \theta}{A} = \frac{2(22.136)}{\frac{9.8}{6}} \sin 90^\circ = 19.166 \text{ seconds}$$

Acceleration to achieve initial velocity V

$$A = \frac{V^2}{2R} = \frac{22.136^2}{2 \times 2} = 122.5 \text{ meters/second}^2$$

Force required for launch

$$F = mA = 100(122.5) = 12500 \text{ Newtons}$$

Kinetic Energy (KE)

$$KE = \frac{1}{2} m V^2 = \frac{1}{2} (100) (22.136)^2 = 24500 \text{ Joules}$$

DESCRIPTION OF PROGRAM

The following program is written in FORTRAN and is compiled on a FORTRAN type 5 compiler. The program calculates the velocity necessary for the sand bag to travel a distance of x meters on the lunar surface if it is launched at an angle of 45 degrees. The program also calculates the time for the sandbag to cover the distance as well as the maximum height above the lunar surface. Also included in the calculations is the force required to launch the sandbag and the kinetic energy required for the launch. The program does many iterations for different distances of travel as well as distances of acceleration.

PROGRAM VELOC 74/990 OPT=0,ROUND= A/ S/ M/-D,-DS FTN 5.1+642 87/06,
DO=-LONG/-OT,ARG=-COMMON/-FIXED,CS= USER/-FIXED,DB= TB/ SB/ SL/ ER/-ID/ PMD/-ST,-AL,PL
FTN5,I=ME4182,L=LUST,DB.

```

1      PROGRAM VELOC (INPUT,OUTPUT,TAPE5=INPUT,TAPE6=OUTPUT)
2      C
3      C
4      C      PROGRAM TO CALCULATE THE INTIAL VELOCITY NEEDED TO
5      C      PROPELL A SANDBAG A DISTANCE OF X METERS ON THE MOON
6      C      ALSO WILL CALCULATE THE TIME REQUIRED AND THE MAX HEIGHT OF
7      C      THE SANDBAG ALONG WITH THE KINETIC ENERGY
8      C
9      C
10     C
11     C      ***** VARIABLES *****
12     C
13     C
14     C      INTEGER I, J
15     C      REAL T(500),YMAX(500),V(500),X(500),A1(500),F(500),K(500),NU(500)
16     C
17     C
18     C
19     C
20     C      R-LENGTH OF ACCELERATION
21     C      X-DISTANCE SANDBAG TRAVELS ACROSS LUNAR SURFACE
22     C      V-VELOCITY NEEDED TO REACH X DISTANCE
23     C      T-TIME REQUIRED TO TRAVEL DISTANCE
24     C      YMAX-MAXIMUM HEIGHT ABOVE THE HORIZONTAL AXIS
25     C      F-FORCE REQUIRED TO ACHIEVE INITIAL VELOCITY
26     C      KE-KINETIC ENERGY REQUIRED TO LAUNCH BAG
27     C      NUMBER-NUMBER OF LAUNCHES PER MINUTE FOR X DISTANCE
28     C      A1-ACCELERATION OF GRAVITY ON THE LUNAR SURFACE
29     C      M-MASS OF SAND BAG=100KG
30     C      P-POWER SUPPLY=10 KW
31     C      O=ANGLE OF LAUNCH
32     C
33     C
34     C      ***** DEFINE VARIABLES *****
35     C
36     C
37     C      L=4
38     C      M=100
39     C      E=10
40     C      N=300/E
41     C      P=10000
42     C
43     C      A=9.8/6
44     C      O=3.14159265/4
45     C
46     C
47     C      ***** PROGRAM BODY *****
48     C
49     C
50     C      DO 1 R=1,L
51     C      DO 10 I=1,N
52     C      X(I)=I*E
53     C      V(I)=SQRT(X(I)*A/SIN(2*O))
54     C      T(I)=2*V(I)*SIN(O)/A
55     C      YMAX(I)=V(I)*SIN(O)*T(I)/2 -(.5*A*T(I)*T(I)*.25)

```

```

56      A1(I)=V(I)**2/(R*2)
57      F(I)=M*A1(I)
58      K(I)=.5*M*V(I)**2
59      NU(I)=P/K(I)*60
60      10 CONTINUE
61      C
62      C
63      C
64      C      ***** PRINT OUT *****
65      C
66      C
67      PRINT*, ' '
68      PRINT*, ' ***** OUTPUT ***** '
69      PRINT*, ' '
70      PRINT*, ' MASS OF BAG IS ---- 100 KG '
71      PRINT*, ' R--- LENGTH OF CYLINDER = ',R,' METERS '
72      PRINT*, ' X--- DISTANCE SAND BAG TRAVELS '
73      PRINT*, ' V--- INTIAL VELOCITY NEEDED '
74      PRINT*, ' T--- TIME REQUIRED TO TRAVEL DISTANCE '
75      PRINT*, ' YMAX --- MAXIMUM HEIGHT ABOVE THE HORIZONTAL AXIS '
76      PRINT*, ' F--- FORCE REQUIRED TO ACHIEVE INITIAL VELOCITY '
77      PRINT*, ' KE--- KINETIC ENERGY REQUIRED TO LAUNCH BAG '
78      PRINT*, ' NUMBER--- NUMBER OF LAUNCHES/MINUTE FOR 10KW SUPPLY '
79      PRINT*, ' '
80      PRINT*, ' '
81      PRINT*, '      X      V      T      YMAX      F      KE
82      +  NUMBER '
83      PRINT*, '      (M)      (M/S)      (S)      (M)      (N)      (J) '
84      PRINT*, ' '
85      C
86      C
87      DO 15 J=1,N
88      PRINT20, X(J),V(J),T(J),YMAX(J),F(J),K(J),NU(J)
89      15 CONTINUE
90      C
91      1 CONTINUE
92      C
93      C
94      C      ***** END OF PROGRAM *****
95      C
96      20 FORMAT (2X,F6.1,2X,F6.3,2X,F6.3,2X,F6.3,3X,F10.3,3X,F8.2,2X,F6.2)
97      END

```

--VARIABLE MAP--(LO=A)

NAME	ADDRESS	BLOCK	PROPERTIES	TYPE	SIZE	NAME	ADDRESS	BLOCK
A	10560B			REAL		N	10556B	
A1	4633B			REAL	500	NU	7567B	
E	10555B			REAL		O	10561B	
F	5617B			REAL	500	P	10557B	
I	711B			INTEGER		R	10562B	
J	712B			INTEGER		T	713B	
K	6603B			REAL	500	V	2663B	
L	10553B			INTEGER		X	3647B	
M	10554B			INTEGER		YMAX	1677B	

***** OUTPUT *****

MASS OF BAG IS ---- 100 KG
 R--- LENGTH OF CYLINDER = 1. METERS
 X--- DISTANCE SAND BAG TRAVELS
 V--- INTIAL VELOCITY NEEDED
 T--- TIME REQUIRED TO TRAVEL DISTANCE
 YMAX --- MAXIMUM HEIGHT ABOVE THE HORIZONTAL AXIS
 F--- FORCE REQUIRED TO ACHIEVE INITIAL VELOCITY
 KE--- KINETIC ENERGY REQUIRED TO LAUNCH BAG
 NUMBER--- NUMBER OF LAUNCHES/MINUTE FOR 10KW SUPPLY

X (M)	V (M/S)	T (S)	YMAX (M)	F (N)	KE (J)	NUMBER
10.0	4.041	3.499	2.500	816.667	816.67	734.69
20.0	5.715	4.949	5.000	1633.333	1633.33	367.35
30.0	7.000	6.061	7.500	2450.000	2450.00	244.90
40.0	8.083	6.999	10.000	3266.667	3266.67	183.67
50.0	9.037	7.825	12.500	4083.333	4083.33	146.94
60.0	9.899	8.571	15.000	4900.000	4900.00	122.45
70.0	10.693	9.258	17.500	5716.667	5716.67	104.96
80.0	11.431	9.897	20.000	6533.333	6533.33	91.84
90.0	12.124	10.498	22.500	7350.000	7350.00	81.63
100.0	12.780	11.066	25.000	8166.667	8166.67	73.47
110.0	13.404	11.606	27.500	8983.333	8983.33	66.79
120.0	14.000	12.122	30.000	9800.000	9800.00	61.22
130.0	14.572	12.617	32.500	10616.667	10616.67	56.51
140.0	15.122	13.093	35.000	11433.333	11433.33	52.48
150.0	15.652	13.553	37.500	12250.000	12250.00	48.98
160.0	16.166	13.997	40.000	13066.667	13066.67	45.92
170.0	16.663	14.428	42.500	13883.333	13883.33	43.22
180.0	17.146	14.846	45.000	14700.000	14700.00	40.82
190.0	17.616	15.253	47.500	15516.667	15516.67	38.67
200.0	18.074	15.649	50.000	16333.333	16333.33	36.73
210.0	18.520	16.036	52.500	17150.000	17150.00	34.99
220.0	18.956	16.413	55.000	17966.667	17966.67	33.40
230.0	19.382	16.782	57.500	18783.333	18783.33	31.94
240.0	19.799	17.143	60.000	19600.000	19600.00	30.61
250.0	20.207	17.496	62.500	20416.667	20416.67	29.39
260.0	20.607	17.843	65.000	21233.333	21233.33	28.26
270.0	21.000	18.183	67.500	22050.000	22050.00	27.21
280.0	21.385	18.516	70.000	22866.667	22866.67	26.24
290.0	21.764	18.844	72.500	23683.333	23683.33	25.33
300.0	22.136	19.166	75.000	24500.000	24500.00	24.49

***** OUTPUT *****

MASS OF BAG IS ---- 100 KG
 R--- LENGTH OF CYLINDER = 2. METERS
 X--- DISTANCE SAND BAG TRAVELS
 V--- INTIAL VELOCITY NEEDED
 T--- TIME REQUIRED TO TRAVEL DISTANCE
 YMAX --- MAXIMUM HEIGHT ABOVE THE HORIZONTAL AXIS
 F--- FORCE REQUIRED TO ACHIEVE INITIAL VELOCITY
 KE--- KINETIC ENERGY REQUIRED TO LAUNCH BAG
 NUMBER--- NUMBER OF LAUNCHES/MINUTE FOR 10KW SUPPLY

X (M)	V (M/S)	T (S)	YMAX (M)	F (N)	KE (J)	NUMBER
10.0	4.041	3.499	2.500	408.333	816.67	734.69
20.0	5.715	4.949	5.000	816.667	1633.33	367.35
30.0	7.000	6.061	7.500	1225.000	2450.00	244.90
40.0	8.083	6.999	10.000	1633.333	3266.67	183.67
50.0	9.037	7.825	12.500	2041.667	4083.33	146.94
60.0	9.899	8.571	15.000	2450.000	4900.00	122.45
70.0	10.693	9.258	17.500	2858.333	5716.67	104.96
80.0	11.431	9.897	20.000	3266.667	6533.33	91.84
90.0	12.124	10.498	22.500	3675.000	7350.00	81.63
100.0	12.780	11.066	25.000	4083.333	8166.67	73.47
110.0	13.404	11.606	27.500	4491.667	8983.33	66.79
120.0	14.000	12.122	30.000	4900.000	9800.00	61.22
130.0	14.572	12.617	32.500	5308.333	10616.67	56.51
140.0	15.122	13.093	35.000	5716.667	11433.33	52.48
150.0	15.652	13.553	37.500	6125.000	12250.00	48.98
160.0	16.166	13.997	40.000	6533.333	13066.67	45.92
170.0	16.663	14.428	42.500	6941.667	13883.33	43.22
180.0	17.146	14.846	45.000	7350.000	14700.00	40.82
190.0	17.616	15.253	47.500	7758.333	15516.67	38.67
200.0	18.074	15.649	50.000	8166.667	16333.33	36.73
210.0	18.520	16.036	52.500	8575.000	17150.00	34.99
220.0	18.956	16.413	55.000	8983.333	17966.67	33.40
230.0	19.382	16.782	57.500	9391.667	18783.33	31.94
240.0	19.799	17.143	60.000	9800.000	19600.00	30.61
250.0	20.207	17.496	62.500	10208.333	20416.67	29.39
260.0	20.607	17.843	65.000	10616.667	21233.33	28.26
270.0	21.000	18.183	67.500	11025.000	22050.00	27.21
280.0	21.385	18.516	70.000	11433.333	22866.67	26.24
290.0	21.764	18.844	72.500	11841.667	23683.33	25.33
300.0	22.136	19.166	75.000	12250.000	24500.00	24.49

***** OUTPUT *****

MASS OF BAG IS ---- 100 KG
R--- LENGTH OF CYLINDER = 3. METERS
X--- DISTANCE SAND BAG TRAVELS
V--- INTIAL VELOCITY NEEDED
T--- TIME REQUIRED TO TRAVEL DISTANCE
YMAX --- MAXIMUM HEIGHT ABOVE THE HORIZONTAL AXIS
F--- FORCE REQUIRED TO ACHIEVE INITIAL VELOCITY
KE--- KINETIC ENERGY REQUIRED TO LAUNCH BAG
NUMBER--- NUMBER OF LAUNCHES/MINUTE FOR 10KW SUPPLY

X (M)	V (M/S)	T (S)	YMAX (M)	F (N)	KE (J)	NUMBER
10.0	4.041	3.499	2.500	272.222	816.67	734.69
20.0	5.715	4.949	5.000	544.444	1633.33	367.35
30.0	7.000	6.061	7.500	816.667	2450.00	244.90
40.0	8.083	6.999	10.000	1088.889	3266.67	183.67
50.0	9.037	7.825	12.500	1361.111	4083.33	146.94
60.0	9.899	8.571	15.000	1633.333	4900.00	122.45
70.0	10.693	9.258	17.500	1905.556	5716.67	104.96
80.0	11.431	9.897	20.000	2177.778	6533.33	91.84
90.0	12.124	10.498	22.500	2450.000	7350.00	81.63

100.0	12.780	11.066	25.000	2722.222	8166.67	73.47
110.0	13.404	11.606	27.500	2994.444	8983.33	66.79
120.0	14.000	12.122	30.000	3266.667	9800.00	61.22
130.0	14.572	12.617	32.500	3538.889	10616.67	56.51
140.0	15.122	13.093	35.000	3811.111	11433.33	52.48
150.0	15.652	13.553	37.500	4083.333	12250.00	48.98
160.0	16.166	13.997	40.000	4355.556	13066.67	45.92
170.0	16.663	14.428	42.500	4627.778	13883.33	43.22
180.0	17.146	14.846	45.000	4900.000	14700.00	40.82
190.0	17.616	15.253	47.500	5172.222	15516.67	38.67
200.0	18.074	15.649	50.000	5444.444	16333.33	36.73
210.0	18.520	16.036	52.500	5716.667	17150.00	34.99
220.0	18.956	16.413	55.000	5988.889	17966.67	33.40
230.0	19.382	16.782	57.500	6261.111	18783.33	31.94
240.0	19.799	17.143	60.000	6533.333	19600.00	30.61
250.0	20.207	17.496	62.500	6805.556	20416.67	29.39
260.0	20.607	17.843	65.000	7077.778	21233.33	28.26
270.0	21.000	18.183	67.500	7350.000	22050.00	27.21
280.0	21.385	18.516	70.000	7622.222	22866.67	26.24
290.0	21.764	18.844	72.500	7894.444	23683.33	25.33
300.0	22.136	19.166	75.000	8166.667	24500.00	24.49

***** OUTPUT *****

MASS OF BAG IS ---- 100 KG
R---- LENGTH OF CYLINDER = 4. METERS
X---- DISTANCE SAND BAG TRAVELS
V---- INTIAL VELOCITY NEEDED
T---- TIME REQUIRED TO TRAVEL DISTANCE
YMAX --- MAXIMUM HEIGHT ABOVE THE HORIZONTAL AXIS
F---- FORCE REQUIRED TO ACHIEVE INITIAL VELOCITY
KE--- KINETIC ENERGY REQUIRED TO LAUNCH BAG
NUMBER--- NUMBER OF LAUNCHES/MINUTE FOR 10KW SUPPLY

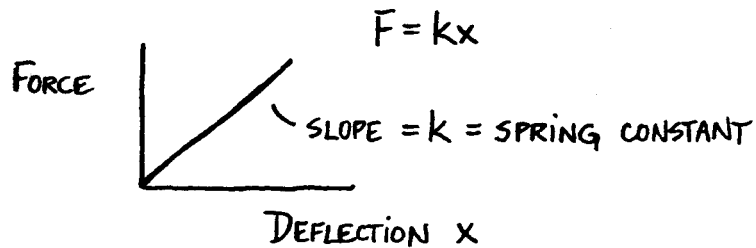
X (M)	V (M/S)	T (S)	YMAX (M)	F (N)	KE (J)	NUMBER
10.0	4.041	3.499	2.500	204.167	816.67	734.69
20.0	5.715	4.949	5.000	408.333	1633.33	367.35
30.0	7.000	6.061	7.500	612.500	2450.00	244.90
40.0	8.083	6.999	10.000	816.667	3266.67	183.67
50.0	9.037	7.825	12.500	1020.833	4083.33	146.94
60.0	9.899	8.571	15.000	1225.000	4900.00	122.45
70.0	10.693	9.258	17.500	1429.167	5716.67	104.96
80.0	11.431	9.897	20.000	1633.333	6533.33	91.84
90.0	12.124	10.498	22.500	1837.500	7350.00	81.63
100.0	12.780	11.066	25.000	2041.667	8166.67	73.47
110.0	13.404	11.606	27.500	2245.833	8983.33	66.79
120.0	14.000	12.122	30.000	2450.000	9800.00	61.22
130.0	14.572	12.617	32.500	2654.167	10616.67	56.51
140.0	15.122	13.093	35.000	2858.333	11433.33	52.48
150.0	15.652	13.553	37.500	3062.500	12250.00	48.98
160.0	16.166	13.997	40.000	3266.667	13066.67	45.92
170.0	16.663	14.428	42.500	3470.833	13883.33	43.22
180.0	17.146	14.846	45.000	3675.000	14700.00	40.82
190.0	17.616	15.253	47.500	3879.167	15516.67	38.67
200.0	18.074	15.649	50.000	4083.333	16333.33	36.73
210.0	18.520	16.036	52.500	4287.500	17150.00	34.99
220.0	18.956	16.413	55.000	4491.667	17966.67	33.40

230.0	19.382	16.782	57.500	4695.833	18783.33	31.94
240.0	19.799	17.143	60.000	4900.000	19600.00	30.61
250.0	20.207	17.496	62.500	5104.167	20416.67	29.39
260.0	20.607	17.843	65.000	5308.333	21233.33	28.26
270.0	21.000	18.183	67.500	5512.500	22050.00	27.21
280.0	21.385	18.516	70.000	5716.667	22866.67	26.24
290.0	21.764	18.844	72.500	5920.833	23683.33	25.33
300.0	22.136	19.166	75.000	6125.000	24500.00	24.49

SPRING DESIGN CALCULATIONS:

GIVEN : ENERGY REQUIRED TO LAUNCH 100 kg SANDBAG
300 METERS = 32150 JOULES

- SPRING FORCE CURVE:



- TOTAL SPRING ENERGY:

$$\text{ENERGY} = \int_0^x F = \frac{1}{2} kx^2$$

- TOTAL SPRING CONSTANT:

$$k_{\text{TOTAL}} = \frac{2(\text{ENERGY})}{x^2} = \frac{2(32150 \text{ J})}{(2 \text{ meters})^2}$$
$$= 16075 \text{ N/m}$$

- INDIVIDUAL SPRINGS

- CHOOSE A WIRE DIAMETER AND A COIL DIAMETER

d = WIRE DIAMETER = 0.017 METERS

D = COIL DIAMETER = 0.18 METERS

- CALCULATE NUMBER OF COILS:

$$N = \frac{\text{SOLID HEIGHT}}{\text{WIRE DIAMETER}} = \frac{1 \text{ METER}}{0.017 \text{ METERS}} = 59 \text{ TURNS}$$

- INDIVIDUAL SPRING CONSTANT:

$$k = \frac{G d^4}{8 D^3 N} = \frac{(77200 \times 10^6 \frac{\text{N}}{\text{m}^2})(0.017 \text{ m})^4}{8 (0.18 \text{ m})^3 (59)} = 2342 \frac{\text{N}}{\text{m}}$$

- SPRING INDEX:

$$C = \frac{D}{d} = \frac{0.18 \text{ m}}{0.017 \text{ m}} = 10.59$$

- SHEAR STRESS MULTIPLICATION FACTOR:

$$K_s = 1 + \frac{0.5}{C} = 1 + \frac{0.5}{10.59} = 1.0472$$

- WAHL CORRECTION FACTOR:

$$K = \frac{4C-1}{4C-4} + \frac{0.615}{C} = 1.1363$$

- FATIGUE STRENGTH REDUCTION FACTOR:

$$K_c = \frac{K}{K_s} = 1.08$$

- LOAD ON SPRING:

$$P = kx = (2342 \frac{\text{N}}{\text{m}})(2 \text{ m}) = 4684 \text{ N}$$

- SHEAR STRESS ON SPRING (CORRECTED) :

$$\tau_c = K_c \left(\frac{8PD}{\pi d^3} \right) = 1.085 \left(\frac{8(4684 \text{ N}_m)(0.18 \text{ m})}{\pi (0.017 \text{ m})^3} \right)$$
$$= 474 \text{ MPa}$$

NOTE: $474 \text{ MPa} < 485 \text{ MPa} =$ MAXIMUM RECOMMENDED
DESIGN STRESS FOR
CHROMIUM-VANADIUM
SPRING STEEL.

- TOTAL NUMBER OF SPRINGS:

$$\text{NUMBER} = \frac{K_{\text{TOTAL}}}{K} = \frac{16075 \text{ N}_m}{2342 \text{ N}_m} = 6.86$$

\therefore 7 SPRINGS

DESCRIPTION OF PROGRAM

The following program is written in FORTRAN and is compiled on a FORTRAN type 5 compiler. The program determines the optimal number of springs to use in the design of the launcher mechanism. In addition, the program calculates the mass of all the springs combined. The program is described with comment statements throughout. Attached to the program is example output obtained from the computer. The number of springs used in this project is circled in the output.

PROGRAM SPRING 74/990 OPT=0,ROUND= A/ S/ M/-D,-DS FTN 5.1+642 87/06
DO=-LONG/-OT,ARG=-COMMON/-FIXED,CS= USER/-FIXED,DB= TB/ SB/ SL/ ER/-ID/ PMD/-ST,-AL,PL
FTN5,I=SPRING,L=LIST,DB.

```

1      PROGRAM SPRING (INPUT,OUTPUT)
2      C
3      C      THE FOLLOWING PROGRAM WILL DETERMINE THE OPTIMAL NUMBER AND
4      C      SIZE OF SPRINGS TO BE USED IN THE DESIGN OF A LUNAR SANDBAG
5      C      LAUNCHER BY VARYING THE WIRE DIAMETER AND THE SPRING COIL
6      C      DIAMETER AND COMPARING THE RESULTING CALCULATIONS TO ACCEPTABLE
7      C      STRESS LIMITATIONS.
8      C
9      C      DECLARE ALL VARIABLES
10     C
11     REAL D,DW,XS,XA,G,DENS,E,KT,N,K,NUMB,C,CF,CFF,CFFF
12     REAL P,TAU,STRESS,VOL1,VOL2,AREA,VOL,MASS
13     INTEGER NUMB1,I,J
14     C
15     C      INITIALIZE ALL GIVEN VARIABLES
16     C
17     PI=3.14159265
18     XS=1.0
19     XA=2.0
20     G=77200.0E+06
21     STRESS=485.0E+06
22     DENS=7850.0
23     C
24     C      CALCULATE THE ENERGY REQUIRED FOR LAUNCH
25     C
26     E=(0.5*130.0*22.136**2)+(130.0*1.635*(0.707*XA))
27     C
28     C      CALCULATE THE TOTAL SPRING CONSTANT REQUIRED TO PROVIDE THE
29     C      ABOVE ENERGY
30     C
31     KT=(2.0*E)/XA**2
32     C
33     C      VARY THE COIL DIAMETER IN A DO LOOP WHILE VARYING
34     C      THE WIRE DIAMETER OF THE SPRING WITHIN THIS LOOP
35     C
36     D=0.08
37     I=1
38     DO 10 I=1,40
39         DW=0.005
40         J=1
41         DO 20 J=1,20
42         C
43         C      CALCULATE THE NUMBER OF COILS
44         C
45         N=XS/DW
46         C
47         C      CALCULATE THE INDIVIDUAL SPRING CONSTANT AND
48         C      DETERMINE THE NUMBER OF SPRINGS REQUIRED
49         C
50         K=(G*DW**4)/(8.0*D**3*N)
51         NUMB=KT/K
52         NUMB1=INT(NUMB)
53         IF((NUMB-NUMB1).GT. 0.0) THEN
54             NUMB1=NUMB1+1
55         ENDIF

```

```

      56          IF (NUMB1 .GT. 20) THEN
      57              GO TO 30
      58          ENDIF
      59          C
      60          C      CALCULATE THE STRESS COEFFICIENTS AND DETERMINE IF THE
      61          C      STRESS ON THE SPRING IS ACCEPTABLE
      62          C
      63              C=D/DW
      64              CF=(4.0*C-1)/(4*C-4)+(0.615/C)
      65              CFF=1+(0.5/C)
      66              CFFF=CF/CFF
      67              P=K*XA
      68              TAU=CFFF*((8.0*P*D)/(PI*DW**3))
      69              IF (TAU .GT. STRESS) THEN
      70                  GO TO 30
      71              ENDIF
      72          C
      73          C      DETERMINE THE VOLUME AND MASS OF THE SPRINGS
      74          C
      75              AREA=NUMB1*(PI*D**2/4.0)
      76              VOL1=(3.2/N)/(2.0*PI*D/2.0)
      77              VOL2=VOL1/3.2
      78              VOL=NUMB1*(PI*DW**2/4.0)/VOL2
      79              MASS=VOL*DENS
      80          C
      81          C      PRINT THE RESULTS
      82          C
      83              PRINT*, 'WIRE DIAMETER=', DW, ' METERS'
      84              PRINT*, 'SPRING DIAMETER=', D, ' METERS'
      85              PRINT*, 'THE NUMBER OF SPRINGS=', NUMB1
      86              PRINT*, 'THE TOTAL MASS=', MASS, ' KILOGRAMS'
      87              PRINT*, 'THE CYLINDRICAL SPRING AREA=', AREA, ' SQUARE METERS'
      88              PRINT*, ' '
      89          30      DW=DW+0.001
      90          20      CONTINUE
      91              D=D+0.005
      92          10      CONTINUE
      93              STOP
      94              END

```

--VARIABLE MAP-- (LO=A)

NAME	ADDRESS	BLOCK	PROPERTIES	TYPE	SIZE	NAME	ADDRESS	BLOCK
AREA	352B			REAL		KT	335B	
C	341B			REAL		MASS	354B	
CF	342B			REAL		N	336B	
CFF	343B			REAL		NUMB	340B	
CFFF	344B			REAL		NUMB1	355B	
D	326B			REAL		P	345B	
DENS	333B			REAL		PI	360B	
DW	327B			REAL		STRESS	347B	
E	334B			REAL		TAU	346B	
G	332B			REAL		VOL	353B	
I	356B			INTEGER		VOL1	350B	
J	357B			INTEGER		VOL2	351B	
K	337B			REAL		XA	331B	

WIRE DIAMETER=.015 METERS
SPRING DIAMETER=.175 METERS
THE NUMBER OF SPRINGS=12
THE TOTAL MASS=610.1266056755 KILOGRAMS
THE CYLINDRICAL SPRING AREA=.2886338247187 SQUARE METERS

WIRE DIAMETER=.016 METERS
SPRING DIAMETER=.175 METERS
THE NUMBER OF SPRINGS=9
THE TOTAL MASS=488.1012845404 KILOGRAMS
THE CYLINDRICAL SPRING AREA=.2164753685391 SQUARE METERS

WIRE DIAMETER=.014 METERS
SPRING DIAMETER=.18 METERS
THE NUMBER OF SPRINGS=19
THE TOTAL MASS=927.3924406267 KILOGRAMS
THE CYLINDRICAL SPRING AREA=.483491108835 SQUARE METERS

WIRE DIAMETER=.015 METERS
SPRING DIAMETER=.18 METERS
THE NUMBER OF SPRINGS=13
THE TOTAL MASS=679.8553606098 KILOGRAMS
THE CYLINDRICAL SPRING AREA=.330809706045 SQUARE METERS

WIRE DIAMETER=.016 METERS
SPRING DIAMETER=.18 METERS
THE NUMBER OF SPRINGS=10
THE TOTAL MASS=557.8300394747 KILOGRAMS
THE CYLINDRICAL SPRING AREA=.25446900465 SQUARE METERS

WIRE DIAMETER=.017 METERS
SPRING DIAMETER=.18 METERS
THE NUMBER OF SPRINGS=7
THE TOTAL MASS=414.8860918593 KILOGRAMS
THE CYLINDRICAL SPRING AREA=.178128303255 SQUARE METERS

WIRE DIAMETER=.014 METERS
SPRING DIAMETER=.185 METERS
THE NUMBER OF SPRINGS=20
THE TOTAL MASS=1003.319307111 KILOGRAMS
THE CYLINDRICAL SPRING AREA=.5376050422312 SQUARE METERS

WIRE DIAMETER=.015 METERS
SPRING DIAMETER=.185 METERS
THE NUMBER OF SPRINGS=14
THE TOTAL MASS=752.4894803331 KILOGRAMS
THE CYLINDRICAL SPRING AREA=.3763235295619 SQUARE METERS

WIRE DIAMETER=.016 METERS
SPRING DIAMETER=.185 METERS
THE NUMBER OF SPRINGS=11
THE TOTAL MASS=630.6578501839 KILOGRAMS
THE CYLINDRICAL SPRING AREA=.2956827732272 SQUARE METERS

WIRE DIAMETER=.017 METERS
SPRING DIAMETER=.185 METERS
THE NUMBER OF SPRINGS=8
THE TOTAL MASS=487.3265205967 KILOGRAMS
THE CYLINDRICAL SPRING AREA=.2150420168925 SQUARE METERS

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AXIAL FORCE ROD:

$$n P_{cr} = C \pi^2 E I / (l)^2$$

$$n P_{cr} = \pi^3 E (\rho) (d_o^4 - d_i^4) / (128 l)$$

for cylinder, fixed-free, $f = 27200N$

with max length = 6 meters, aluminum rod:

$$3.5 \times 10^{-6} = d_o^4 - d_i^4$$

d_i	d_o
-------	-------

0.0 cm	4.32cm
--------	--------

2cm	4.4cm
-----	-------

4cm	5.0 cm
-----	--------

4.5cm	5.3cm
-------	-------

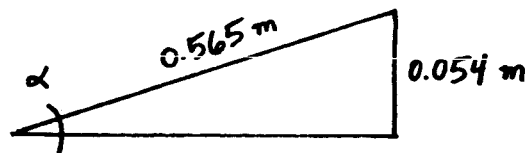
LAUNCHER VOLUME AND MASS CALCULATIONS:

- SPRINGS:

$$\text{AREA OF WIRE} = \frac{\pi(0.017\text{ m})^2}{4} = 2.27 \times 10^{-4} \text{ m}^2$$

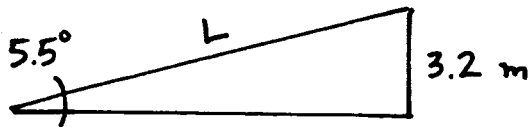
LENGTH OF WIRE :

1 coil



$$\therefore \alpha = 5.5^\circ$$

WHOLE WIRE



$$L = 33.4 \text{ m}$$

$$\text{VOLUME} = (33.4 \text{ m})(2.27 \times 10^{-4} \text{ m}^2) = 7.6 \times 10^{-3} \text{ m}^3$$

$$\text{MASS} = (7.6 \times 10^{-3} \text{ m}^3)(7850 \frac{\text{kg}}{\text{m}^3}) = 59.5 \text{ kg}$$

$$\text{TOTAL MASS} = 7(59.5 \text{ kg}) = \underline{417 \text{ kg}}$$

• BAG HOLDER ASSEMBLY

- BUCKET:

$$\text{BASE - VOLUME} = 1075 \text{ cm}^3$$

$$\begin{aligned}\text{MASS} &= (1075 \text{ cm}^3)(1.44 \text{ g/cm}^3) \\ &= 1.55 \text{ kg}\end{aligned}$$

$$\text{SIDES - VOLUME} = 6210 \text{ cm}^3$$

$$\begin{aligned}\text{MASS} &= (6210 \text{ cm}^3)(1.44 \text{ g/cm}^3) \\ &= 8.94 \text{ kg}\end{aligned}$$

- GUIDANCE RODS:

$$\text{VOLUME} = 13800 \text{ cm}^3$$

$$\begin{aligned}\text{MASS} &= (13800 \text{ cm}^3)(1.44 \text{ g/cm}^3) \\ &= 19.8 \text{ kg}\end{aligned}$$

- EXTENDED ARMS:

$$\text{VOLUME} = 945 \text{ cm}^3$$

$$\begin{aligned}\text{MASS} &= (945 \text{ cm}^3)(1.44 \text{ g/cm}^3) \\ &= 1.36 \text{ kg}\end{aligned}$$

$$\text{TOTAL MASS OF BAG HOLDER} = \underline{30.1 \text{ kg}}$$

- SPRING HOUSINGS:

VOLUME -

$$ID = 0.185 \text{ m}$$

$$OD = 0.200 \text{ m}$$

$$VOLUME = 0.0145 \text{ m}^3$$

$$MASS = 7 (0.0145 \text{ m}^3) (1440 \frac{\text{kg}}{\text{m}^3}) = \underline{146.2 \text{ kg}}$$

- SUPPORTS :

$$VOLUME = 495 \text{ cm}^3$$

$$MASS = (495 \text{ cm}^3) (1.44 \frac{\text{g}}{\text{cm}^3}) = \underline{0.7 \text{ kg}}$$

- WASHERS :

$$VOLUME = .00025 \text{ m}^3$$

$$MASS = (7850 \frac{\text{kg}}{\text{m}^3}) (2.5 \times 10^{-4} \text{ m}^3) = \underline{2 \text{ kg}}$$

- AXIAL FORCE ROD :

$$VOLUME: OD = 0.05 \text{ m}$$

$$ID = 0.0 \text{ m}$$

$$L = 7.5 \text{ m}$$

$$VOLUME = 0.0053 \text{ m}^3$$

$$MASS = (0.0053 \text{ m}^3) (2700 \frac{\text{kg}}{\text{m}^3}) = \underline{14.3 \text{ kg}}$$

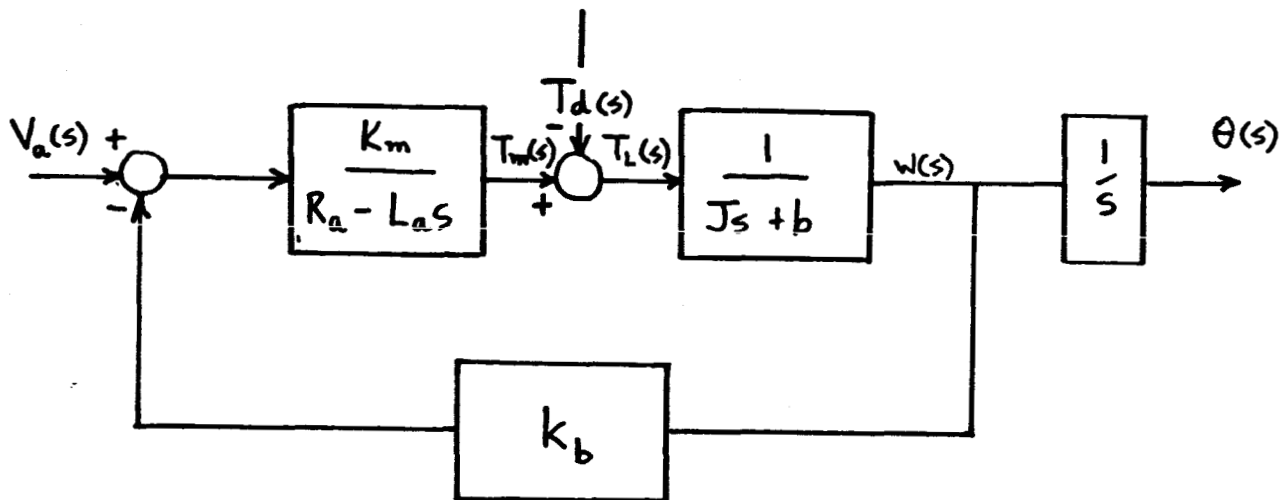
CALCULATION OF MOTOR PARAMETERS FOR COCKING LAUNCH SYSTEM:

- NEED 2 METERS IN APPROXIMATELY 60 SECONDS
- SPOOL ≈ 0.05 METERS ≈ 2.0 inches IN DIAMETER
- CIRCUMFERENCE = $\pi D = 0.157$ METERS
- REVOLUTIONS = $\frac{2}{\text{CIRCUMFERENCE}} = 12.73$
- ANGULAR VELOCITY = $\omega = \frac{12.7 \text{ REV}}{50 \text{ SEC}} = 0.2546 \text{ REV/SEC}$
 $= 15.28 \text{ RPM}$
 $= 1.6 \text{ RAD/SEC}$
- FORCE OF SPRINGS = $k_{\text{TOTAL}} \times 2 \text{ m}$
 $= (16075 \text{ N/m})(2\text{m}) = 32150 \text{ N}$
- TORQUE = $(.05 \text{ m})(32150 \text{ N}) = 1607 \text{ N}\cdot\text{m}$
- POWER = $T\omega = (1607 \text{ N}\cdot\text{m})(1.6 \text{ RAD/SEC})$
 $= 2572 \text{ W}$
 $= 3.4 \text{ HP}$

CONTROLS:

SYSTEM MODELING - FEEDBACK SYSTEM:

- ARMATURE CONTROLLED DC MOTOR

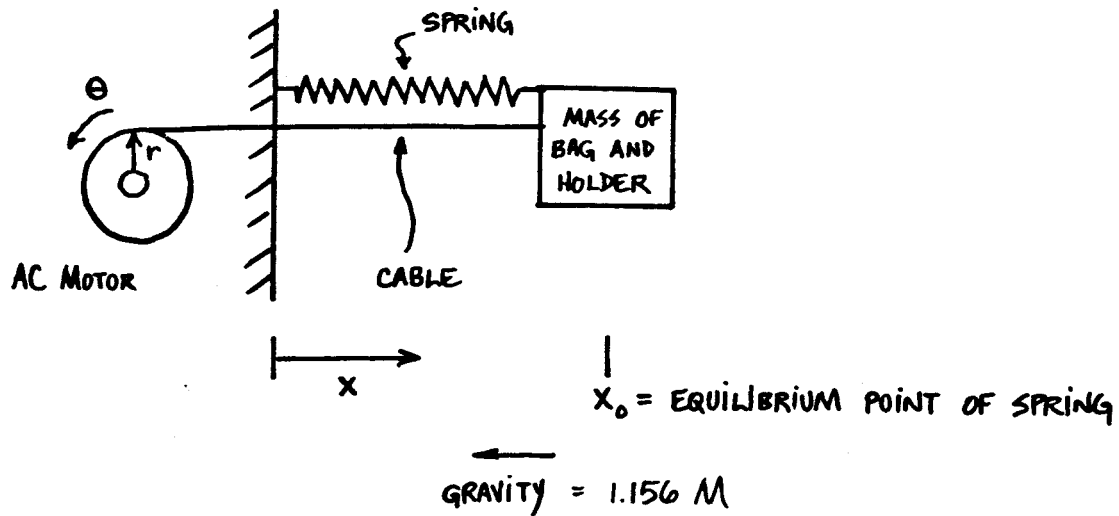


WHERE :

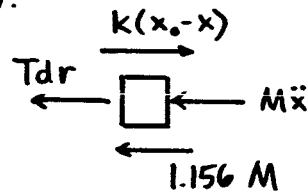
- $V_a(s)$ = ARMATURE VOLTAGE
- K_m = MOTOR CONSTANT
- R_a = ARMATURE RESISTANCE
- L_a = ARMATURE INDUCTANCE
- J = MOTOR INERTIA
- b = MOTOR FRICTION
- K_b = BACK emf CONSTANT

- $T_m(s)$ = TORQUE OF MOTOR
- $T_L(s)$ = TORQUE OF LOAD
- $T_d(s)$ = DISTURBANCE TORQUE

AND: $T_m = T_L + T_d$



FBD:



$$\Sigma F = 0$$

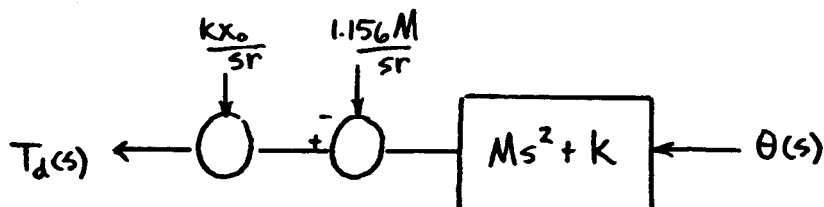
$$Kx_0 - Kx(r) - M \ddot{x}(r) - 1.156 M - rT_d(r) = 0$$

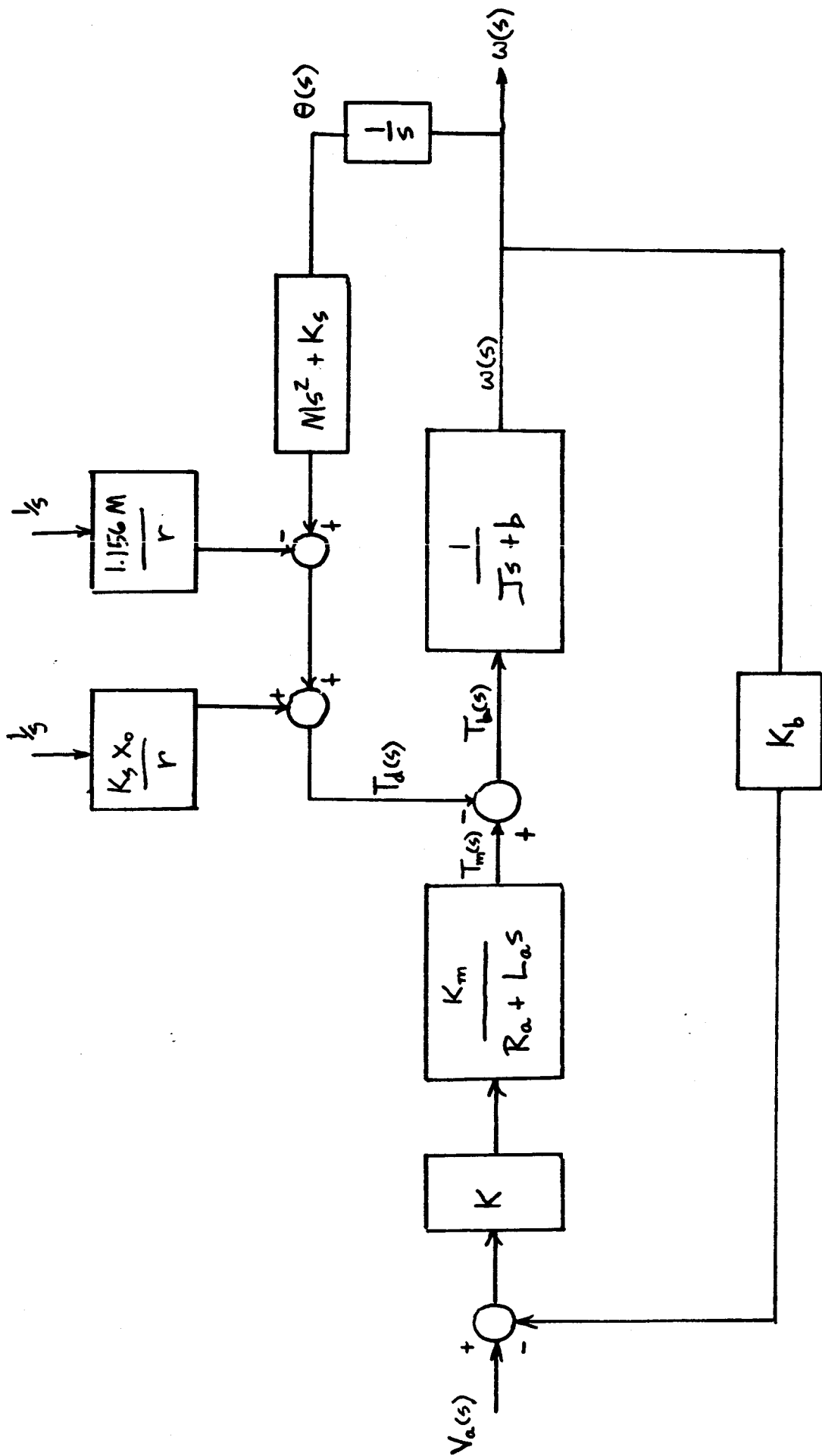
$$\frac{Kx_0}{s} - kx(s) - s^2 Mx(s) - \frac{1.156 M}{s} - rT_d(s) = 0$$

$$T_d(s)r = -x(s)(Ms^2 + K) + \frac{Kx_0}{s} - \frac{1.156 M}{s}$$

BUT: $X(s) = -\Theta(s)r$

$$\therefore T_d(s) = \Theta(s)(Ms^2 + k) + \frac{Kx_0}{sr} - \frac{1.156 M}{sr}$$





CATCHER CALCULATIONS:

Fabric Calculations

$$\text{Denier (D)} = 1000$$

$$\text{Denier between } 840 \rightarrow 920$$

$$\text{Design requires Denier} = 880$$

$$\text{Number of Yarns/inch (N)}$$

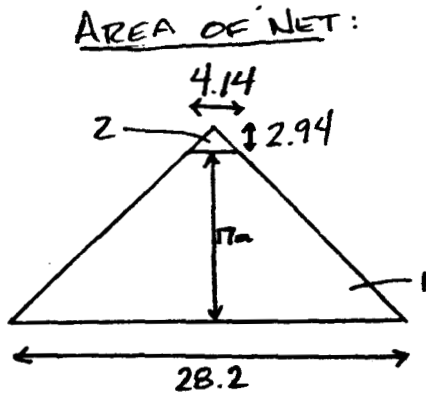
$$N \sqrt{D} = 880$$

$$N \sqrt{1000} = 880$$

$$N = 28 \text{ Yarns/inch} = 1102 \text{ Yarns/meter}$$

$$\text{Strength (S)}$$

$$\begin{aligned} S &= N D \times 9.2 / 453.6 = 28 \times 1000 \times 9.2 / 453.6 = 568 \text{ lbs/in} \\ &= 99511.811 \text{ lbs/meter} \end{aligned}$$



$$A_1 = \frac{1}{2}bh = \frac{1}{2}(28.2)(17.0) = 239.7 \text{ m}^2$$

$$A_2 = \frac{1}{2}bh = \frac{1}{2}(4.14)(2.94) = 12.2 \text{ m}^2$$

$$A_{\text{SIDE}} = 239.7 - 12.2 = 228 \text{ m}^2$$

$$4 \text{ SIDES} \rightarrow A_{\text{TOT}} = 4(228) = 912 \text{ m}^2$$

DECELERATION OF BAG DATA

ACCELERATION OF BAG AT LAUNCHER = 140 m/s^2
 WE WOULD LIKE DECELERATE AT SAME RATE

RUN OUT OF BAG ARRESTER GIVEN BY

$$s = \frac{v^2}{2d}$$

$$= \frac{22.14^2}{2(140)}$$

WHERE v = VELOCITY OF BAG
 $= 22.14$

d = deceleration = 140 m/s^2
 s = distance (RUN OUT)

$$= 1.75 \text{ m (CORRESPONDES TO A DISTANCE OF 5M INTO SIDE OF PYRAMID)}$$

$$\text{ARRESTING FORCE} \equiv F = \frac{s}{g} W = dm$$

WHERE g = gravity constant
 $= 1.6 \text{ m/s}^2$

W = weight

m = mass of sandbag
 $= 110 \text{ kg}$

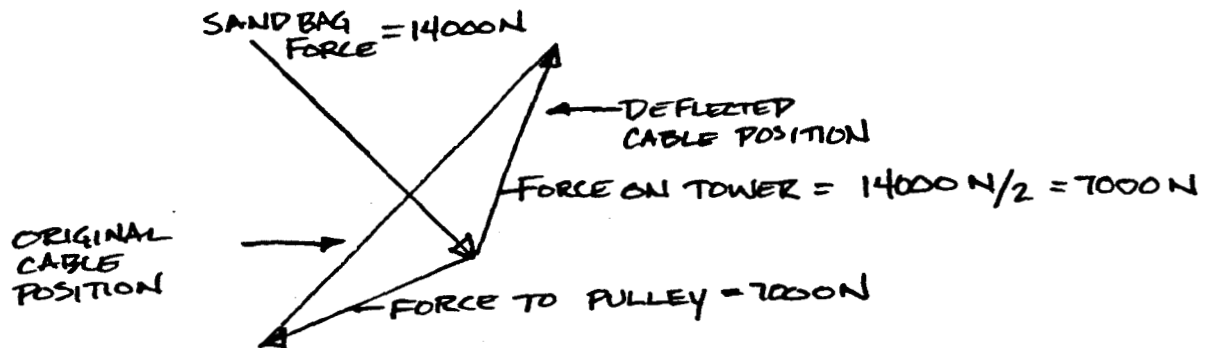
$F = 14000 \text{ N}$ BETWEEN TWO MOTORS & CABLES

THIS LOAD WILL BE CARRIED EITHER BY ONE MOTOR ONLY OR BY BOTH EVENLY (BULLSEYE) OR A COMBINATION OF THE TWO.

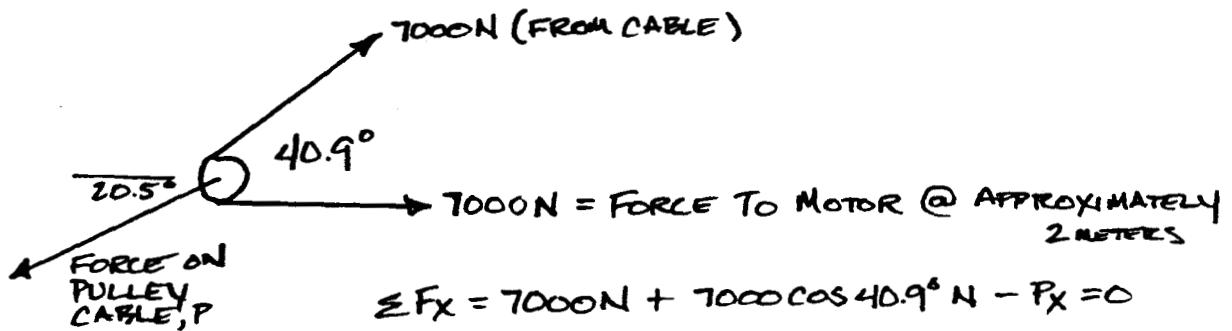
WORST CASE

IN WORST CASE, ONE CABLE WILL BE REQUIRED TO CARRY THE ENTIRE 14000N. THIS WILL BE THE CASE IF THE SANDBAG STRIKES THE CABLE.

TAKING THIS AS A STATICS PROBLEM:



FORCES TO PULLEY & MOTOR



$$\sum F_x = 7000 \text{ N} + 7000 \cos 40.9^\circ \text{ N} - P_x = 0$$

$$P_x = 12300 \text{ N}$$

$$\sum F_y = 7000 \sin 40.9^\circ - P_y = 0$$

$$P_y = 4583 \text{ N}$$

$$P_{TOT} = \sqrt{12300^2 + 4583^2} = \underline{\underline{13100 \text{ N}}} \text{ ON PULLEY CABLE}$$

SNAP-HOOK NET ATTACHMENT STRENGTH

IN WORST CASE, AGAIN WHEN SANDBAG STRIKES ADJACENT TO WIRE CABLE, THE FORCE EXERTED BY BAG IS 14000N. HOOKS ARE SPACED 0.154m (6") APART. WE WILL ASSUME THAT THIS FORCE IS DISTRIBUTED OVER 3 HOOKS. A FACTOR OF SAFETY OF 2 WILL BE USED.

$$\text{FORCE ON HOOK} = 14000/3 = 4670\text{N} = 20800\text{ lbs}_f$$

$$\sigma = \frac{F}{A} = \frac{20800\text{ lbs}}{\pi r^2} = \frac{S}{n} \quad \text{WHERE } S = \text{TENSILE STRENGTH}$$

$n = \text{FACTOR OF SAFETY}$

$S(\text{psi})$	$d(r/2), \text{in}$
106×10^3	.25
53×10^3	.5
35×10^3	.75
26×10^3	1.00

WE WOULD LIKE TO USE ALUMINUM OR ANOTHER LIGHT-WEIGHT MATERIAL WHILE KEEPING THE SIZE REASONABLE. WE COULD USE THE ALUMINUM ALLOY (CAST) A03330-T62 WITH A DIAMETER OF .75 INCHES, BUT THIS WOULD BE RATHER CUMBERSOME. (A03330-T62 HAS $S = 40\text{ kpsi}$) HIGH STRENGTH STEELS HAVE YIELD STRENGTHS WELL ABOVE 106 kpsi @ .25 inch DIAMETER, BUT AT ADDED COST OF WEIGHT. A SOLUTION WOULD BE TO OBTAIN A SNAP HOOK THAT COULD CARRY A LOAD ON THE SNAP AS WELL.

NUMBER OF SNAP-HOOKS

PLACED .154m APART DOWN LENGTH OF 4 CABLES

$$\# = 21.5 \div .154 = 140 \text{ HOOKS}$$

$$\text{TOTAL NUMBER OF HOOKS} = 4(140) = \underline{\underline{560}}$$

NOTE: SAME NUMBER OF LATCHES ON CABLES.

Catcher Support System

The catcher must absorb all of the kinetic energy of the sandbag. The support for the catcher must be designed in accordance with this.

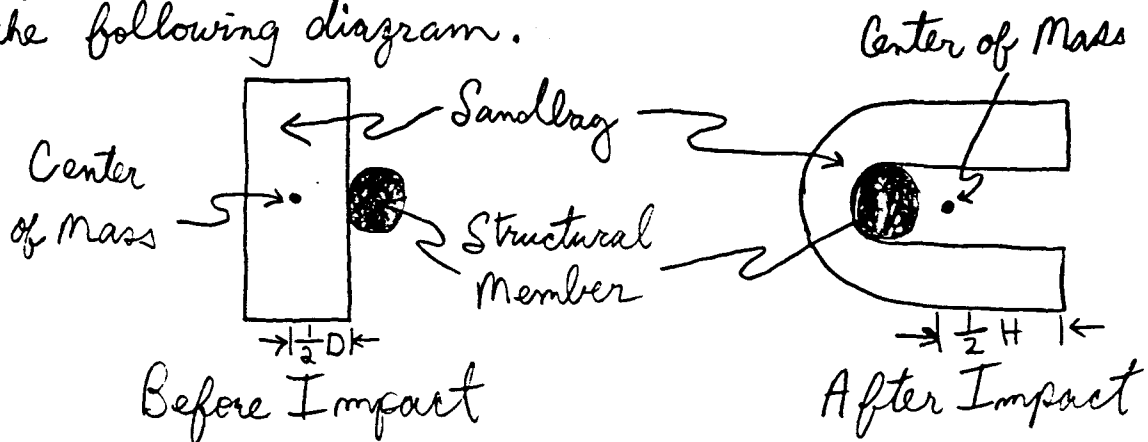
For a sandbag with $\rho = 1.75 \text{ g/cm}^3$, Volume = $.0566 \text{ m}^3$, and Throwing Distance = 300 m .

$$\text{K.E.} = \rho V \frac{gX}{2} = 24,500 \text{ J}$$

The force that the sandbag applies to the support is related to the Kinetic Energy of the bag using the following equation.

$$\text{K.E.} = \text{Work} = (\text{Force}) \times X$$

where X is the distance over which the sandbag is decelerated. The distance X is related to the size and shape of the sandbag, since the sandbag will deform when it hits the structure. This is shown in the following diagram.



From the drawing, the value for X is equal to the distance the center of mass moves.

The shape of the bag in the launcher is that of a cylinder with $D = .24\text{m}$ and $H = 1.25\text{m}$. If we assume that

$$\Delta C.M. = X = \frac{1}{4}H - \frac{1}{2}D$$

then $X = .1925\text{m}$

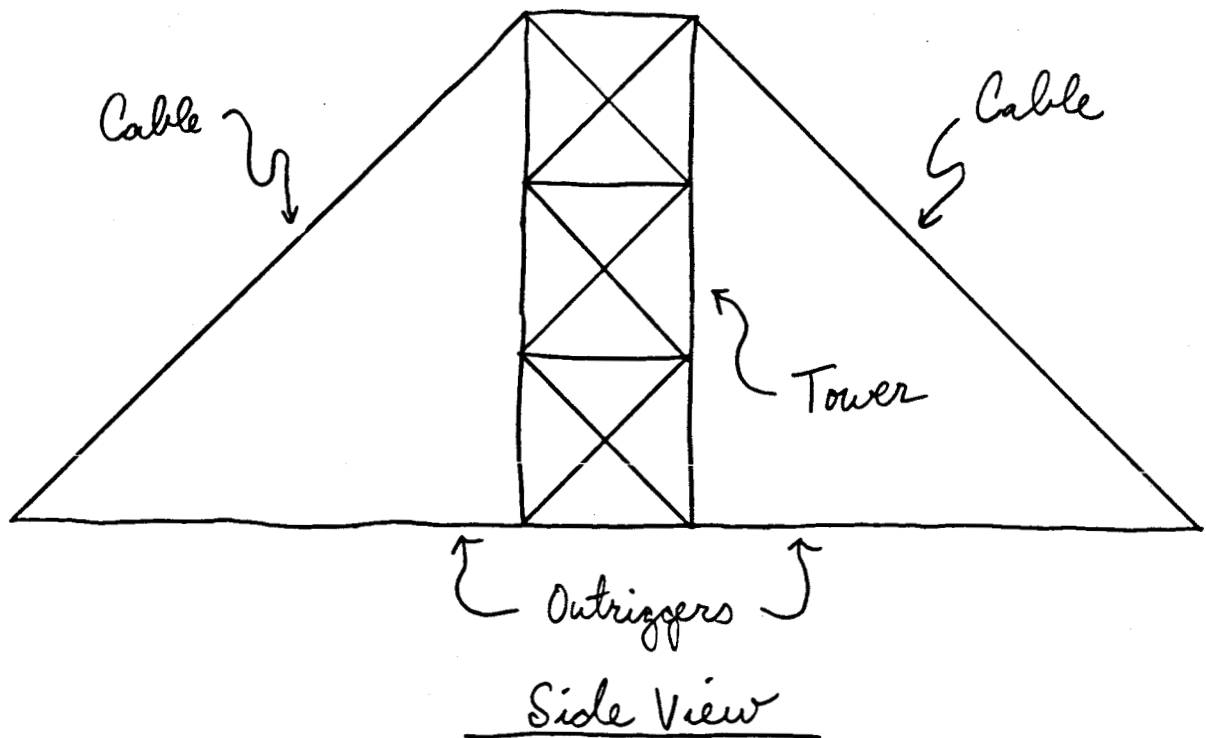
Thus the Force on the structure is

$$F = \frac{24,500\text{J}}{.1925\text{m}} = 127,300\text{N}$$

The preceding analysis was for the case when the sandbag hits the catcher support rather than the catching nets. If the sandbag hits the catching nets, the force on the catcher support will be much less since the deceleration distance will be much greater.

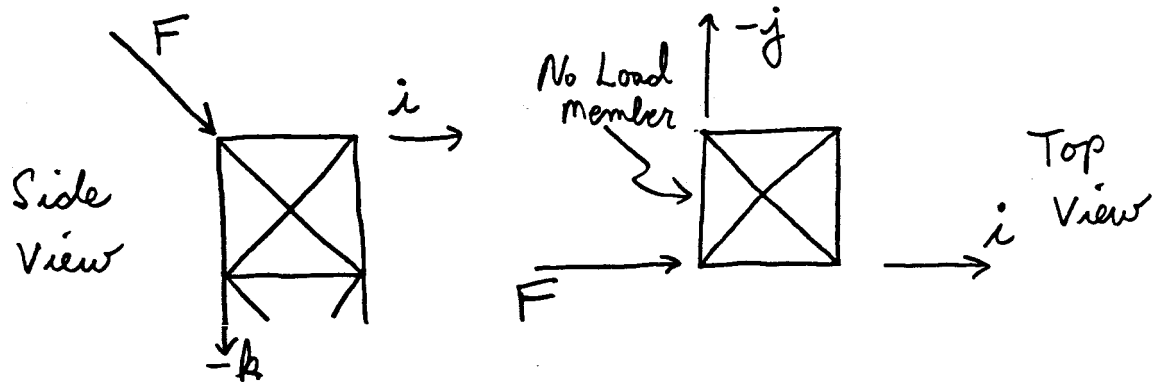
Therefore the worst case occurs when the sandbag strikes the catcher support directly. This is what we must design the support to withstand. Because each component of the catcher support will have its own worst case loading condition, we must determine the worst case for each component and analyze it accordingly. The support for the

Catcher will resemble the following.



Looking at the drawings, we see that the worst case loading condition for the tower occurs when the sandbag hits the top of the tower. If this occurs, the sandbag will either hit a corner of the tower, or one of the members connecting the corners. When the sandbag hits a corner, the force is absorbed by the six members at the corner. When the sandbag hits in between corners, the force is absorbed by two corners or ten members. Thus a sandbag striking a corner of the tower is the worst case loading condition for the tower.

For the case of the canchlag striking the corner, there are many angles at which this can occur. The worst angle is shown below, since in this case one of the members carries no load.



The unit vector representation for the 6 members is:

- | | |
|---------------------|----------------------|
| ① i | ④ $-.707 j - .707 k$ |
| ② $.707 i - .707 k$ | ⑤ $-j$ |
| ③ $-k$ | ⑥ $.707 i - .707 j$ |

$$F = A i - B j$$

Since the force carrying capacity of each member is directly related to its direction, we can sum up the components of all the members.

$$\Sigma = 2.414 i - .707 j - 2.414 k$$

Since there is no force in the j direction, these components can be ignored.

$$\Sigma = 2.414 i - 2.414 k$$

Assuming the bag hits the structure at a 45 degree angle which is the same angle the bag was launched at.

$$F = A i - B k = 127,300 \text{ N}$$

$$F = 90,015 i - 90,015 k \text{ N}$$

Thus the force which each member must take is given by

$$F_m = \frac{90,015 \text{ N}}{2.414} = 37,290 \text{ N}$$

The members of the catcher support will be made out of M-45 aluminum alloy. This material was developed for NASA in the 1960's and has high strength and toughness at very low temperatures.

$$\text{At } T = -200^\circ \text{ F} \quad S_y = 328.9 \text{ MPa}$$

Thus for tensile loading we get

$$F_m = 37,290 \text{ N} = S_y A$$

$$A = \frac{37,290 \text{ N}}{328.9 \times 10^6 \text{ N/m}^2} = 113.4 \times 10^{-6} \text{ m}^2 = 1.134 \text{ cm}^2$$

For a hollow cylinder the following applies.

$$A = \frac{\pi}{4} (D_o^2 - D_i^2) \quad D_o - D_i = 2t$$

$$A = \frac{\pi}{4} (D_o^2 - (D_o - 2t)^2)$$

$$A = \pi (t D_o - t^2)$$

Let $t = \frac{1}{4} D_o$ which should give a good wall thickness.

$$A = \pi \left(\left(\frac{1}{4} D_o \right) D_o - \left(\frac{1}{4} D_o \right)^2 \right)$$

$$A = \pi \left(\frac{3}{16} D_o^2 \right)$$

Applying a safety factor of 2 we get

$$2A = \pi \left(\frac{3}{16} D_o^2 \right)$$

Substituting in the known area we get

$$2(1.134 \text{ cm}^2) = \pi \left(\frac{3}{16} D_o^2 \right)$$

$$D_o = 1.962 \text{ cm}$$

This is the diameter necessary to prevent compressive or tensile failure. We must also check for failure by buckling. This is done below.

$$\left(\frac{L}{R} \right)_1 = \sqrt{\frac{2\pi^2 C E}{S_y}}$$

$$\text{where } E = 71 \times 10^9 \text{ Pa}$$

$$\text{and } S_y = 328.9 \times 10^6 \text{ Pa}$$

For rounded - rounded columns, $C = 1$.

$$\left(\frac{l}{k}\right)_1 = \sqrt{\frac{2\pi^2 (1) (71 \times 10^9 \text{ Pa})}{(328.9 \times 10^6 \text{ Pa})}} = 65.3$$

For hollow circular members

$$\frac{l}{k} = \frac{l}{\sqrt{\frac{(d_o^2 + d_i^2)}{16}}} \quad \text{and} \quad I = \frac{\pi}{64} (d_o^4 - d_i^4)$$

For Euler columns

$$P_{cr} = \frac{C \pi^2 E I}{l^2}$$

$$P_{cr} = \frac{(1) \pi^2 (71 \times 10^9 \text{ Pa}) \frac{\pi}{64} (d_o^4 - d_i^4)}{l^2}$$

$$P_{cr} = \frac{(3.44 \times 10^{10} \text{ Pa}) (d_o^4 - d_i^4)}{l^2}$$

For all members we will let $d_o = 2 d_i = 4t$

$$P_{cr} = \frac{(3.44 \times 10^{10} \text{ Pa}) (d_o^4 - (\frac{d_o}{2})^4)}{l^2}$$

Using a safety factor of 2.

$$2 P_{cr} = \frac{(3.44 \times 10^{10} \text{ Pa}) (\frac{15}{16} d_o^4)}{l^2}$$

$$P_{cr} = (1.613 \times 10^{10} \frac{\text{N}}{\text{m}^2}) \frac{d_o^4}{l^2}$$

For the tower members we have

$$F_m = 37,290 \text{ N}, l_1 = 2.17 \text{ m}, \text{ and } l_2 = 1.54 \text{ m}$$

Applying the Euler equation, where $P_{cr} = F_m$ and $l = l_1$, we get

$$37,290 \text{ N} = \frac{(1.613 \times 10^{10} \frac{\text{N}}{\text{m}^2}) d_o^4}{(2.17 \text{ m})^2}$$

$$d_o = .0574 \text{ m} = 5.74 \text{ cm}$$

Checking to see if Euler equation applied

$$\frac{l}{k} = \frac{217 \text{ cm}}{\sqrt{\frac{(5.74 \text{ cm})^2 + (2.87 \text{ cm})^2}{16}}} = 135$$

Since $l/k > (l/k)_c$, the Euler equation applies. Taking the larger of the two diameters calculated for the tower members we get

Tower

$D_o = 5.74 \text{ cm}$
$t = 1.44 \text{ cm}$

In the preceding analysis to determine the size of the tower members the cables were neglected. This is justified for the following reason.

The direction of the wire using the previously defined

coordinates is

$$\text{wire} = -.577 i + .577 j - .577 k$$

as before neglect the j direction since there is no force in that direction.

$$\text{wire} = -.577 i - .577 k$$

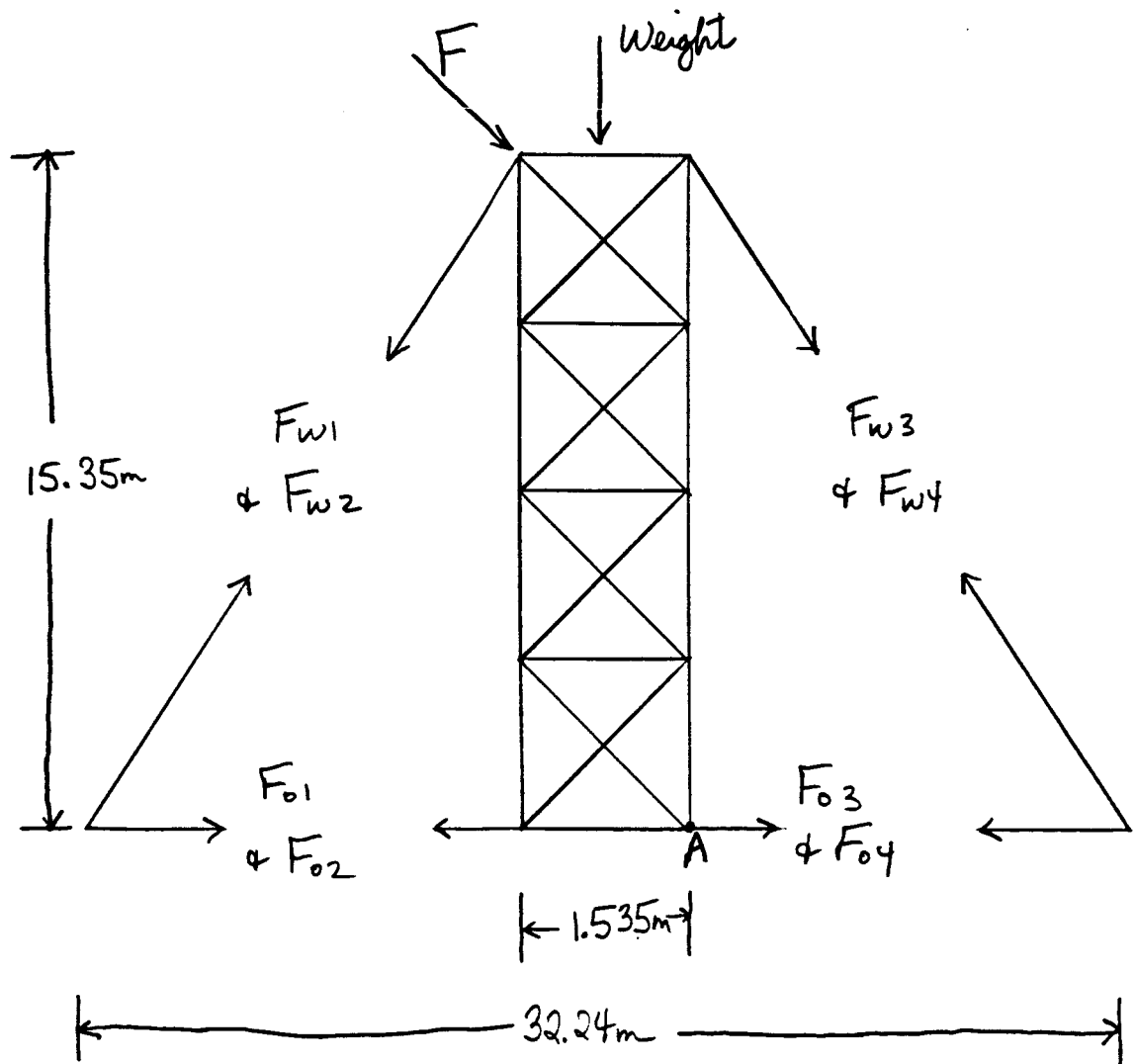
Since the wire can only support a tensile stress, the k component drops out

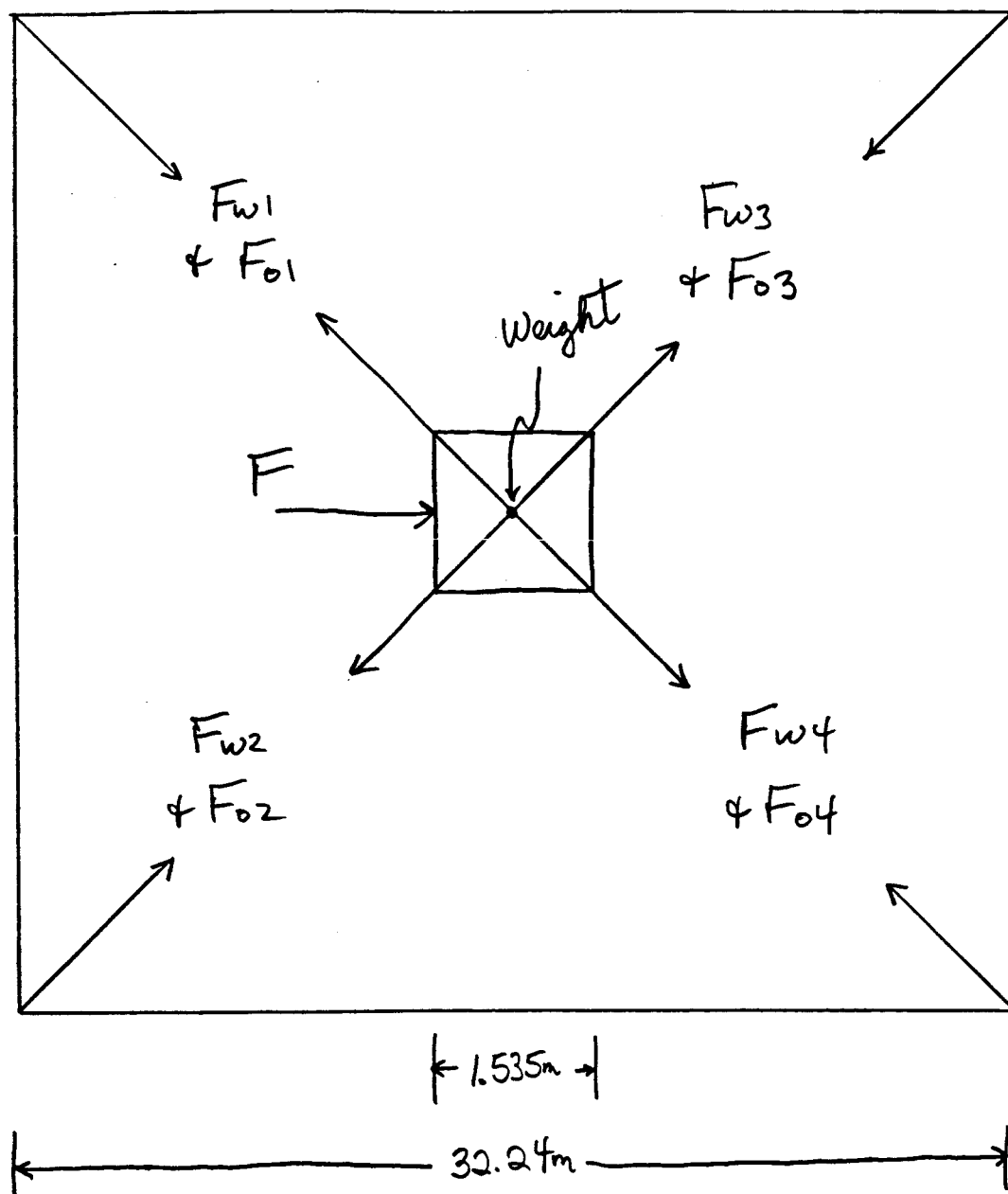
$$\text{wire} = -.577 i$$

Since the wire can only support a force in the i direction, it will decrease the force per member in the horizontal plane, but not affect the force per member in the vertical plane. Since the force per member in the horizontal and vertical planes are the same without the wire, the wire does not decrease the size of the member necessary to prevent failure. It only makes failure in the vertical plane more likely than failure in the horizontal plane. Thus the wires could be neglected for this case.

The next step in the design of the overall catcher structure is the determination of the size of the cables. For the cables, the worst case occurs when the sandbag strikes the top of the tower

perpendicular to one of the outer members on the top face. To analyze this case, the tower will be treated as a free body with only the forces in the cables and outriggers as unknowns. The forces and moments on this system will then be added up to determine the condition for equilibrium. The free body for this analysis is shown below





The weight of the tower must now be determined.

$$\text{Mass}_{\text{Tower}} = (\# \text{ of members}) (\text{mass per member})$$

The number of members can be determined from the

fact that the tower resembles ten cubes stacked on top of each other with members as shown in the previous diagrams.

$$\# \text{ of members} = 24 + 9(18) = 186$$

To calculate the mass per member, the density of pure aluminum will be used as an approximation.

$$\text{Mass per member} = \rho \left(\frac{\pi}{4} (D_o^2 - D_i^2) \right) L$$

$$\text{Mass per member} = (2.70 \text{ g/cm}^3) \left(\frac{\pi}{4} \right) \left((5.74 \text{ cm})^2 - (2.87 \text{ cm})^2 \right) L$$

$$\text{Mass per member} = (52.4 \text{ g/cm}) L$$

There are two different lengths of members making up the tower.

$$L_1 = 1.535 \text{ m} \quad \# = 84, \quad L_2 = 2.171 \text{ m} \quad \# = 102$$

$$\text{Mass} = 52.4 \text{ g/cm} (84(1.535 \text{ m}) + 102(2.171 \text{ m}))$$

$$\text{Mass} = 1.84 \times 10^6 \text{ g} = 1,840 \text{ kg}$$

$$\text{Weight} = 1,840 \text{ kg} \left(\frac{9.81 \text{ m/sec}^2}{6} \right) = \boxed{3,010 \text{ N}}$$

The weight of the tower is therefore only 3.34 % of the force F which was applied to the tower where

$$\% = \frac{3,010 \text{ N}}{90,015 \text{ N}} = 3.34$$

Thus the initial calculation of D_0 is accurate despite the fact that the weight of the tower was neglected.

Now that we know the weight of the tower we can determine the various forces. The directions of these forces are given below.

$$F_{w1} = -.577i + .577j - .577k$$

$$F_{w2} = -.577i - .577j - .577k$$

$$F_{w3} = .577i + .577j - .577k$$

$$F_{w4} = .577i - .577j - .577k$$

$$F_{o1} = -.707i + .707j$$

$$F_{o2} = -.707i - .707j$$

$$F_{o3} = .707i + .707j$$

$$F_{o4} = .707i - .707j$$

$$F = 90,015i - 90,015k \text{ N}$$

$$W = -3,010k \text{ N}$$

$$F_{net} = 90,015i - 93,025k \text{ N}$$

Looking at the F_w 's we must realize that wires cannot support compressive forces. Since the wires are drawn in tension, any F_w component which has the same sign as the F_{net} component will be zero. Also the j terms drop out since there is no force in this direction. This simplification gives.

$$F_{w1} = -0.577 i$$

$$F_{w3} = 0$$

$$F_{w2} = -0.577 i$$

$$F_{w4} = 0$$

The outriggers on the other hand can support a compressive stress. For the outriggers, if the F_o component has the same sign as the F_{net} component then the member is in compression. If the components have opposite signs the member is in tension. Letting the j terms drop out we get.

$$F_{o1} = 0.707 i \quad \textcircled{T}$$

$$F_{o3} = 0.707 i \quad \textcircled{C}$$

$$F_{o2} = 0.707 i \quad \textcircled{T}$$

$$F_{o4} = 0.707 i \quad \textcircled{C}$$

Due to the location of these forces, we can add them together if we assume the outriggers behave the same in compression as in tension.

$$F_{o\ net} = -2.828 i$$

The two wire forces are assumed to be equal and thus can be added.

$$F_{w\ net} = -1.154 i$$

To determine F_o and F_w we must take the moment about point A.

$$\begin{aligned} \sum M_A &= (90,015)(15.35m) - (3,010N)(0.7675m) \\ &\quad - (F_{w\ net})(15.35m) - (90,015N)(1.535m) = 0 \end{aligned}$$

$$F_{w \text{ net}} = 80,860 \text{ N}$$

Summing up the forces in the X direction we get

$$\Sigma F_x = 90,015 \text{ N} - 80,860 \text{ N} - F_{\text{net}} = 0$$

$$F_{\text{net}} = 9,155 \text{ N}$$

Solving for F_o and F_w we get

$$F_o = \frac{9,155 \text{ N}}{2.828} = 3,237 \text{ N} \quad F_w = \frac{80,860 \text{ N}}{1.154} = 70,070 \text{ N}$$

For the wires, we will use solid steel rope with

$$S_y = 1,034 \text{ MPa} = 150 \text{ ksi}$$

$$A = \frac{70,070 \text{ N}}{1,034 \times 10^6 \text{ N/m}^2} = 67.9 \times 10^{-6} \text{ m}^2 = .679 \text{ cm}^2$$

Using a safety factor of 2 we get

$$\frac{\pi}{4} D_o^2 = 2(.679 \text{ cm}^2) = 2A$$

Cables

$$D_o = 1.315 \text{ cm}$$

The weight of the cables can be calculated using $\rho = 7.87 \text{ g/cm}^3$ for steel.

$$\text{Mass per cable} = (7.87 \text{ g/cm}^3) \left(\frac{\pi}{4} \right) (1.315 \text{ cm})^2 L$$

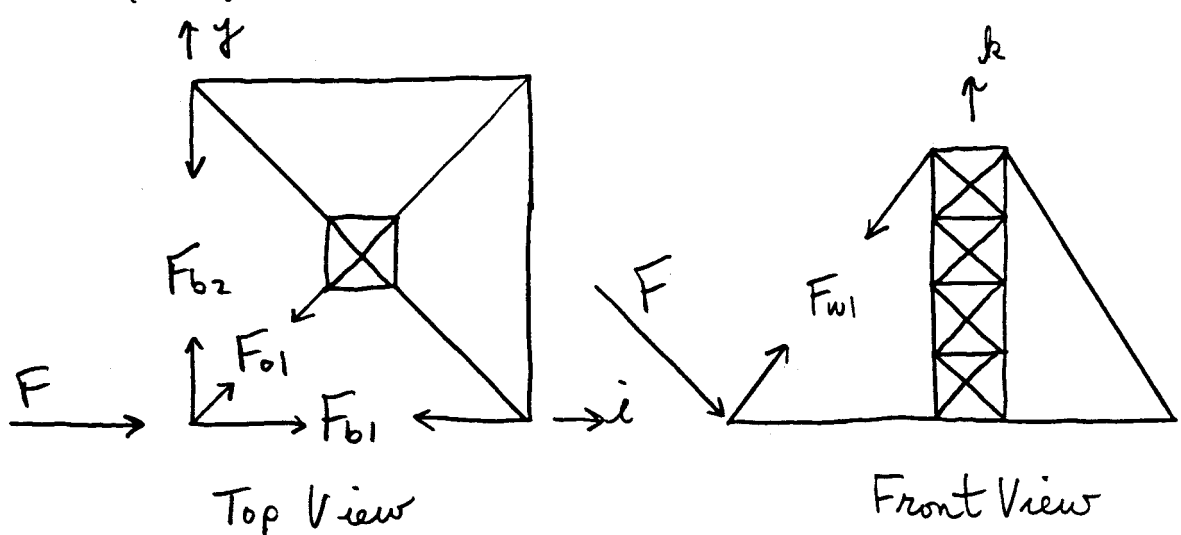
$$\text{Mass per cable} = (10.69 \text{ g/cm}) \ell$$

$$\text{Mass} = 4 (10.69 \text{ g/cm}) (2,659 \text{ cm})$$

$$\text{Mass} = 113.7 \times 10^3 \text{ g} = 113.7 \text{ kg}$$

$$\text{Weight} = 113.7 \text{ kg} \left(\frac{9.81 \text{ m/sec}^2}{6} \right) = \boxed{185.9 \text{ N}}$$

The braces will now be examined. The worst case loading for the braces occurs when the sandbag hits near one of the corners where the cables are connected to the outriggers. The braces will be under the most stress if the sandbag is traveling directly along one of the braces. This case is pictured below.



For this case, the Force of the sandbag is absorbed by two braces, one cable, and one outrigger. These have the following directions.

$$\begin{aligned} F_{b1} &= i & F_{o1} &= .707 i + .707 j \\ F_{b2} &= j & F_{w1} &= .577 i + .577 j + .577 k \end{aligned}$$

$$F = 90,015 i - 90,015 k \text{ N}$$

Since there is no force applied in the j direction, all these components drop out. This gives

$$\begin{aligned} F_{b1} &= i & F_{o1} &= .707 i \\ F_{b2} &= 0 & F_{w1} &= .577 i + .577 k \end{aligned}$$

Since we are only concerned with determining F_{b1} , we can neglect the k components of F_{w1} and F since they do not figure in the determination of F_{b1} . Also, since the i components of F and F_{w1} are in the same direction, the wire is in compression. Since the wire cannot support compression, the i component of F_{w1} drops out. This gives

$$F_{b1} = i \qquad F_{o1} = .707 i$$

$$F = 90,015 i \text{ N}$$

Thus the Force per member is

$$F_m = \frac{90,015 \text{ N}}{(1 + .707)} = 52,733 \text{ N}$$

Now we must evaluate the braces in terms of

compressive stress and buckling.

For compressive stress assuming the braces will be aluminum

$$A = \frac{52,733 \text{ N}}{328.9 \times 10^6 \text{ N/m}^2} = 160.3 \times 10^{-6} \text{ m}^2 = 1.603 \text{ cm}^2$$

using a previously derived formula.

$$\pi \left(\frac{3}{16} D_o^2 \right) = 2(1.603 \text{ cm}^2) = 2A$$

$$D_o = 2.333 \text{ cm}$$

For buckling of the braces we again use a previously derived formula where

$$F = 52,733 \text{ N} \text{ and } l = 32.24 \text{ m}$$

$$52,733 \text{ N} = \frac{1.613 \times 10^{10} \text{ N/m}^2}{(32.24 \text{ m})^2} d_o^4$$

$$d_o = .241 \text{ m} = 24.1 \text{ cm}$$

Since this is much larger than the other value, buckling would be the case of failure and

$$D_o = 24.1 \text{ cm}$$

$$t = 6.03 \text{ cm}$$

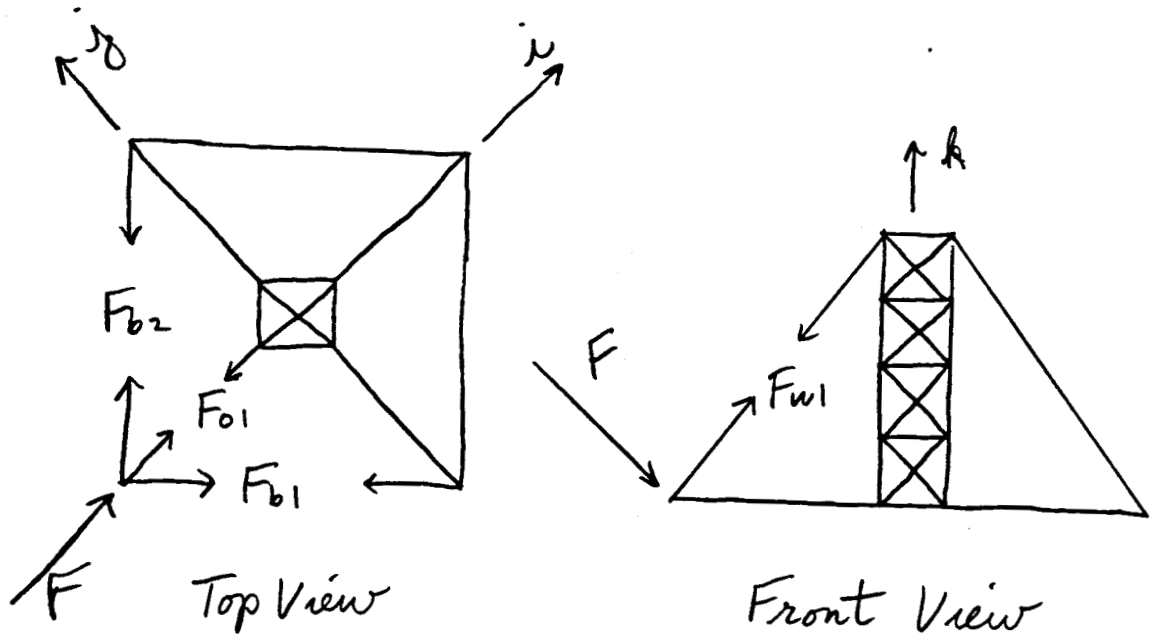
The weight of the four braces will now be calculated

$$\text{Mass} = 4 (2.70 \text{ g/cm}^3) \left(\frac{\pi}{4} \right) ((24.1 \text{ cm})^2 - (12.05 \text{ cm})^2) (3.224 \text{ m})$$

$$\text{Mass} = 11.91 \times 10^6 \text{ g} = 11,910 \text{ kg}$$

$$\text{Weight} = 11,910 \text{ kg} \left(\frac{9.81 \text{ m/sec}^2}{6} \right) = \boxed{19,470 \text{ N}}$$

The outriggers will now be examined. The worst case loading for the outriggers is very similar to that for the braces except that the Force is directed along one of the outriggers at the base of the structure. This is shown below.



For this case the Force is absorbed by two braces, one outrigger, and one wire. These have the following directions.

$$F_{01} = i$$

$$F_{01} = .707 i - .707 j$$

$$F_{w1} = .707 i + .707 k$$

$$F_{02} = .707 i + .707 j$$

$$F = 90,015 i - 90,015 k \text{ N}$$

Since there is no component of F in the j direction, all j components drop out. This gives

$$\begin{aligned} F_{o1} &= i & F_{b1} &= .707 i \\ F_{w1} &= .707 i + .707 k & F_{b2} &= .707 i \end{aligned}$$

The i component of F_{w1} drops out since it is in the same direction as F , which means the wire is in compression. Since F_{o1} has no component in the k direction, we can drop out all k components.

$$F_{o1} = i \quad F_{b1} = .707 i \quad F_{b2} = .707 i$$

$$F = 90,015 i \text{ N}$$

Thus the force per member is

$$F = \frac{90,015 \text{ N}}{(1 + .707 + .707)} = 37,290 \text{ N}$$

Using aluminum to build the outriggers we get the following for compressive stress

$$A = \frac{37,290 \text{ N}}{328.9 \times 10^6 \text{ N/m}^2} = 113.4 \times 10^{-6} \text{ m}^2 = 1.134 \text{ cm}^2$$

Using a previously derived formula

$$\pi \left(\frac{3}{16} D_o^2 \right) = 2(1.134 \text{ cm}^2) = 2A$$

$$D_o = 1.962 \text{ cm}$$

For buckling of the outriggers we have

$$F = 37,290 \text{ N} \quad L = 21.71 \text{ m}$$

$$37,290 \text{ N} = \frac{1.613 \times 10^{10} \text{ N/m}^2}{(21.71 \text{ m})^2} d_o^4$$

$$d_o = .182 \text{ m} = 18.2 \text{ cm}$$

Again, buckling would be the mode of failure so

Outriggers

$$D_o = 18.2 \text{ cm}$$

$$t = 4.55 \text{ cm}$$

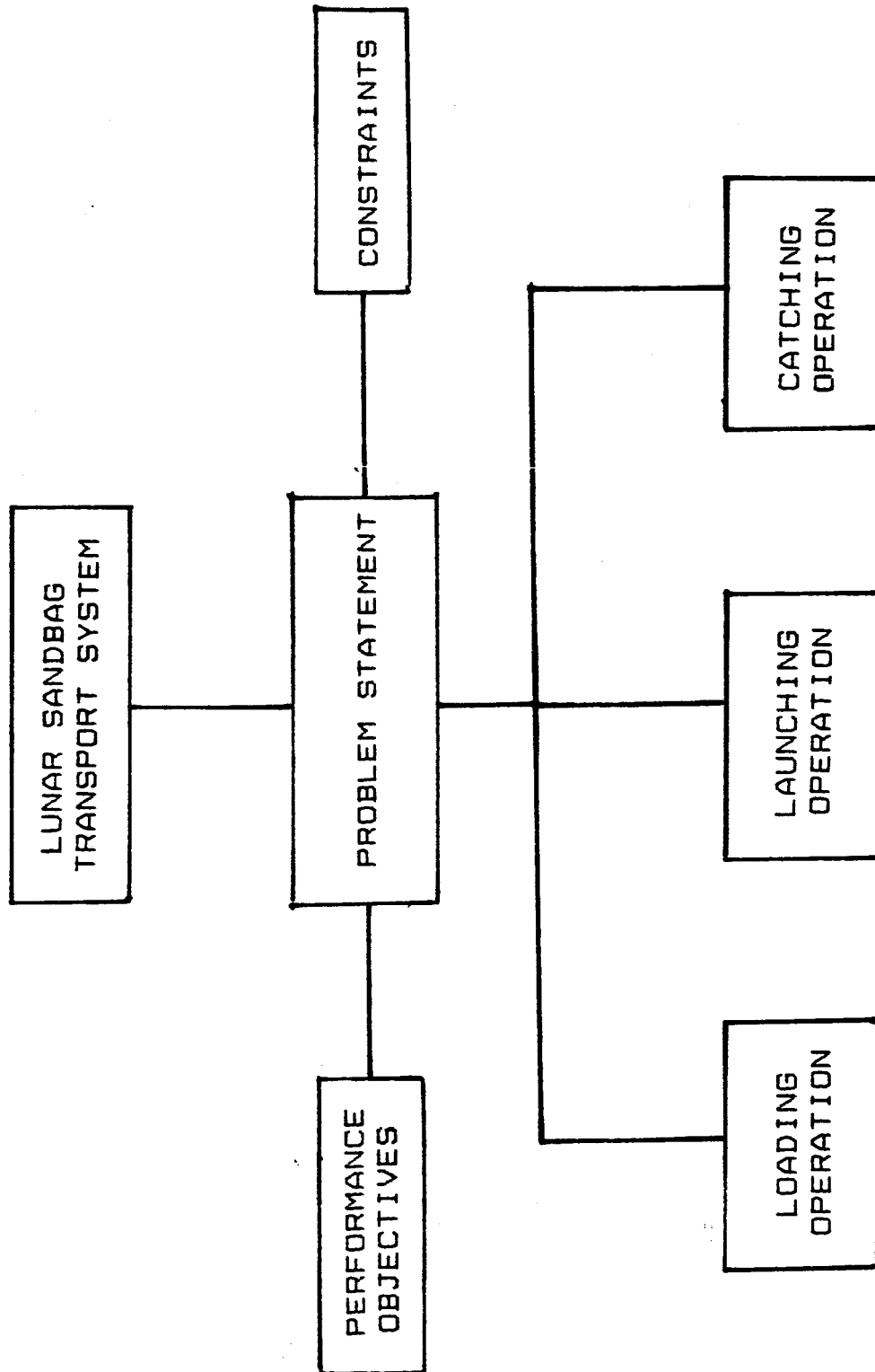
Calculating the weight of the four outriggers

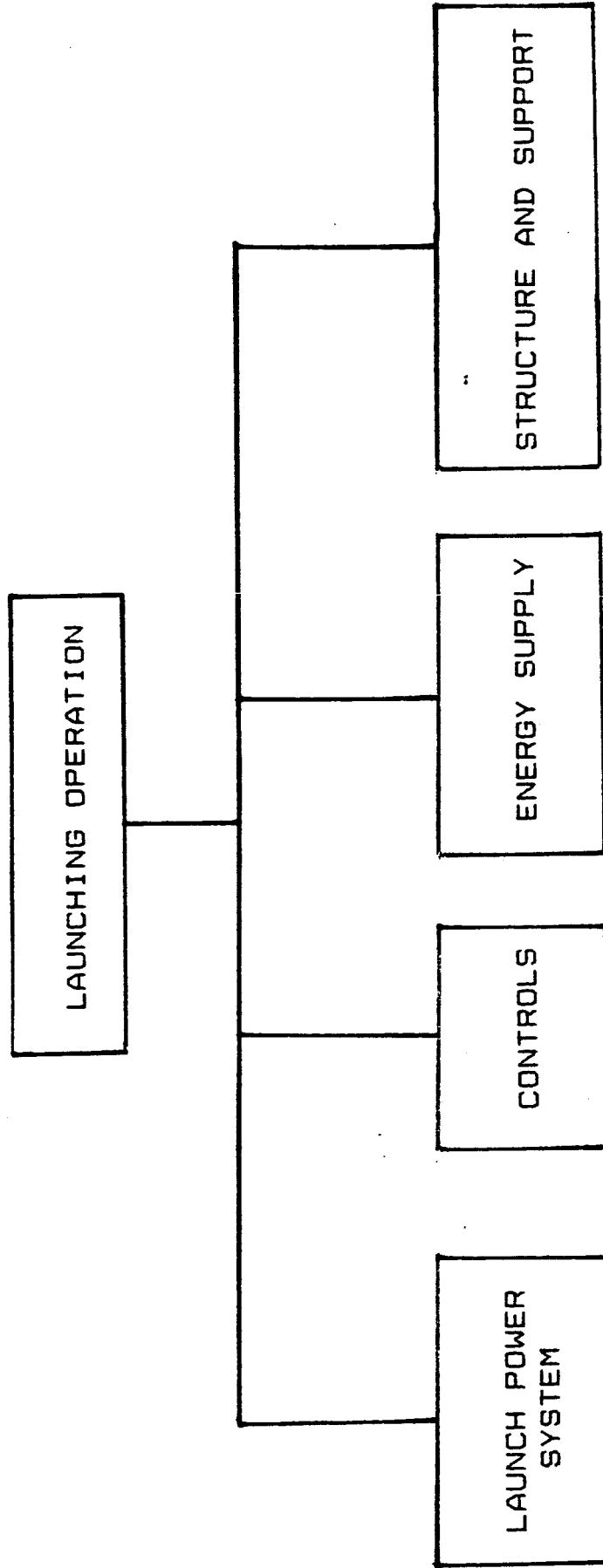
$$\text{Mass} = 4 (2.70 \text{ g/cm}^3 \times \frac{\pi}{4}) ((18.2 \text{ cm})^2 - (9.10 \text{ cm})^2) (21.71 \text{ cm})$$

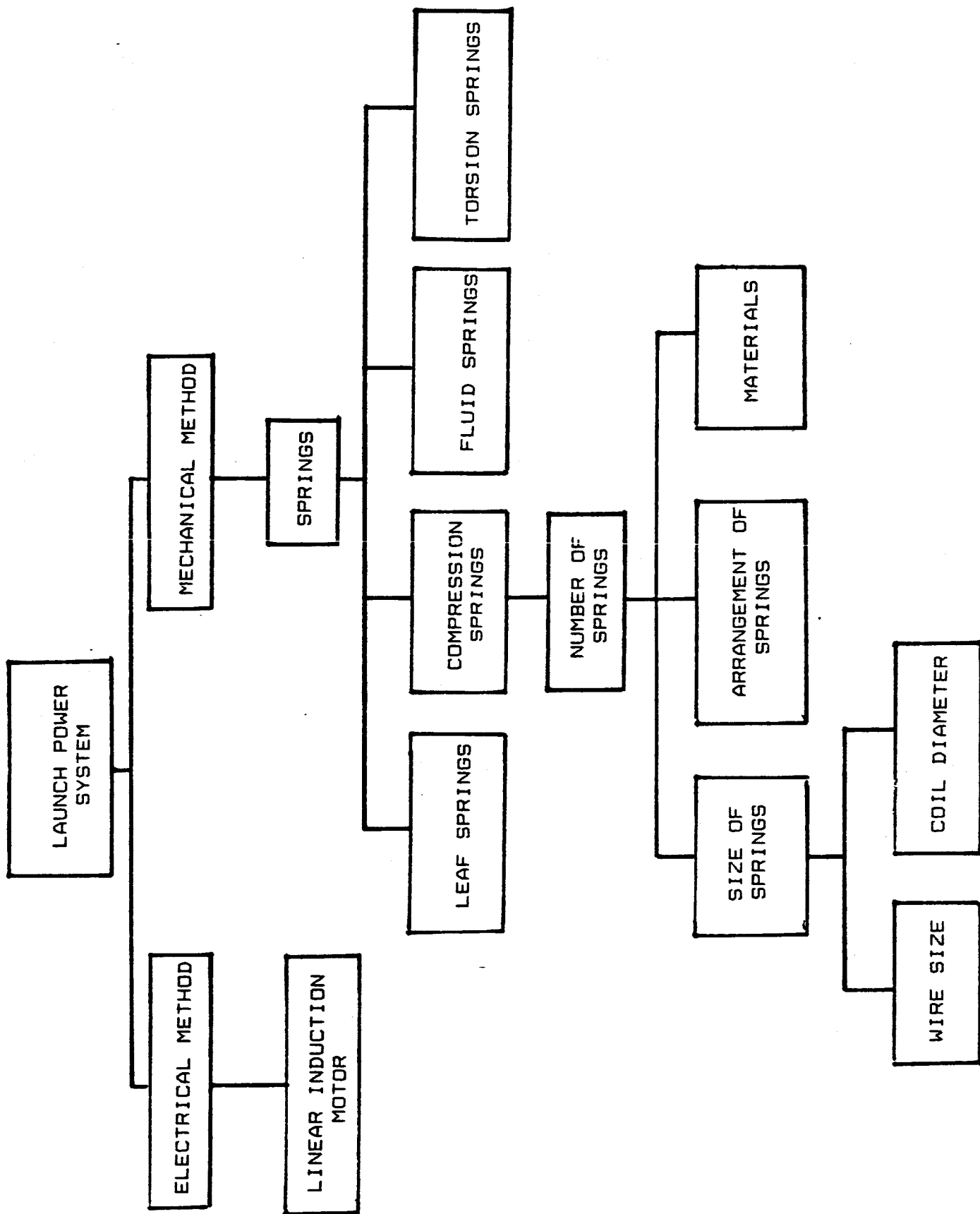
$$\text{Mass} = 4.575 \times 10^6 \text{ g} = 4,575 \text{ kg}$$

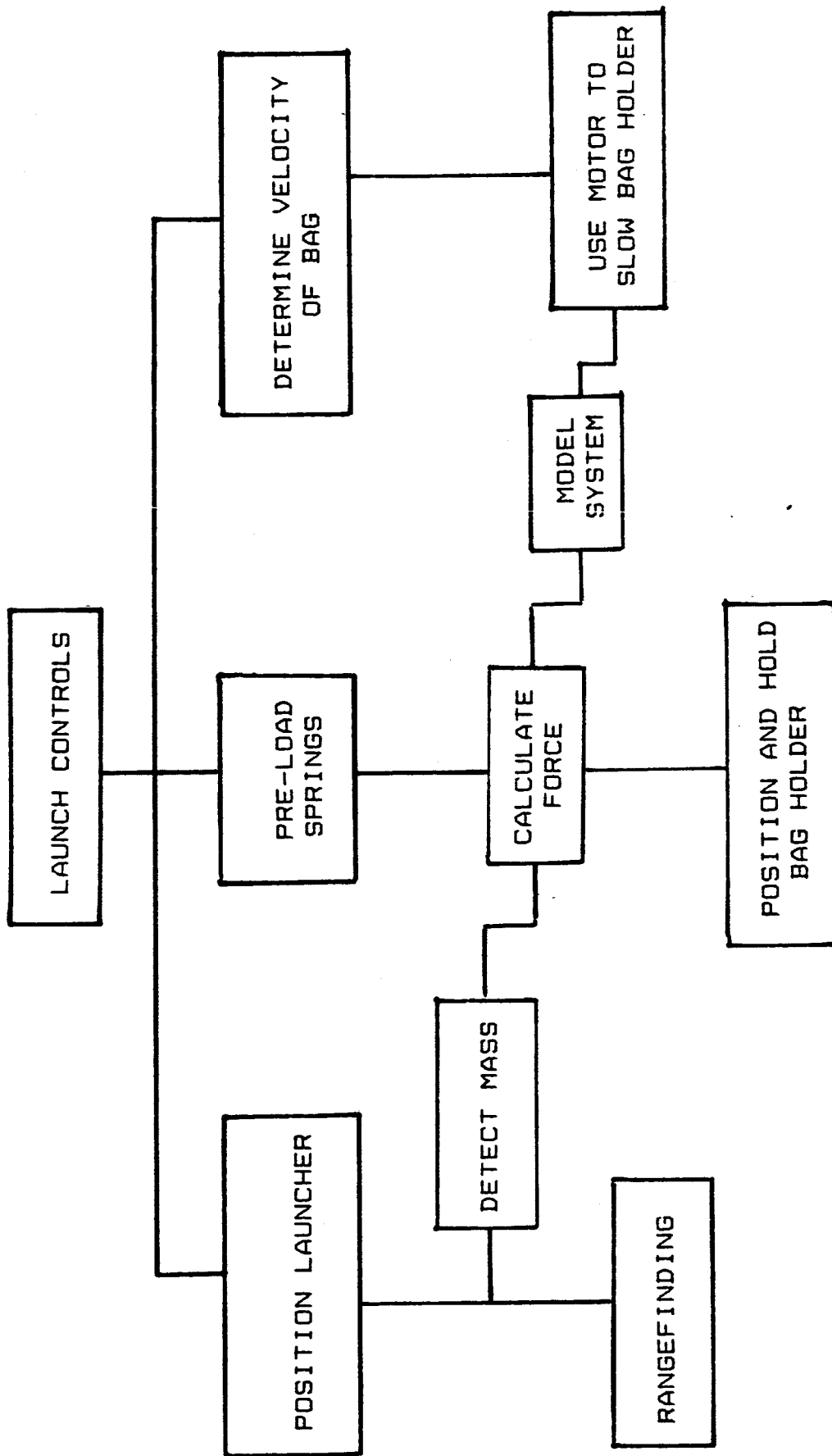
$$\text{Weight} = 4,575 \text{ kg} \left(\frac{9.81 \text{ m/sec}^2}{6} \right) = \boxed{7,480 \text{ N}}$$

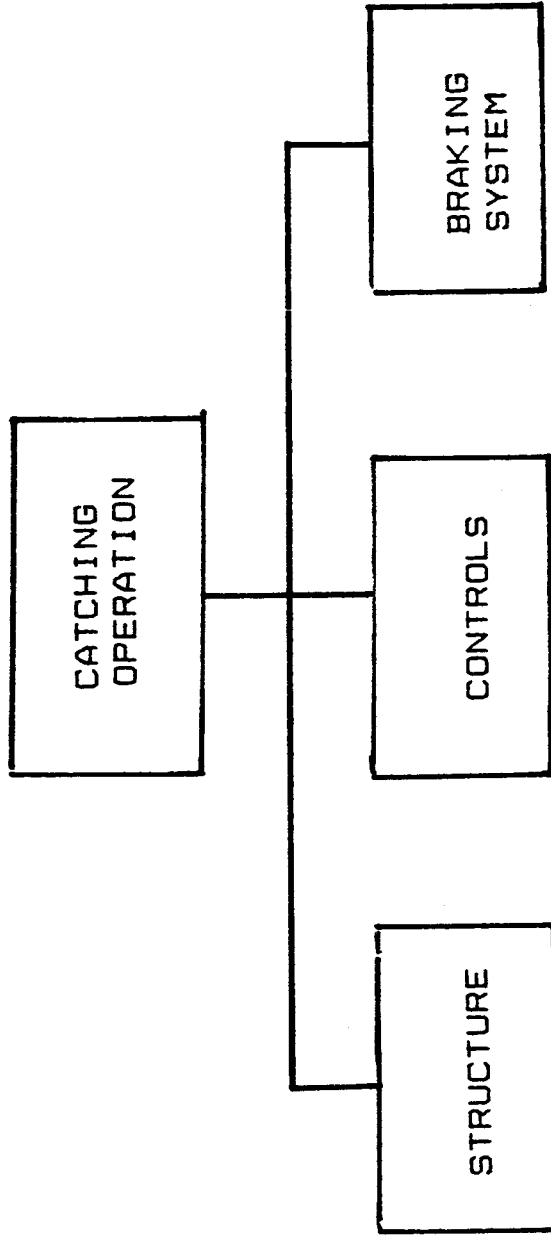
APPENDIX C
DESIGN DECISIONS

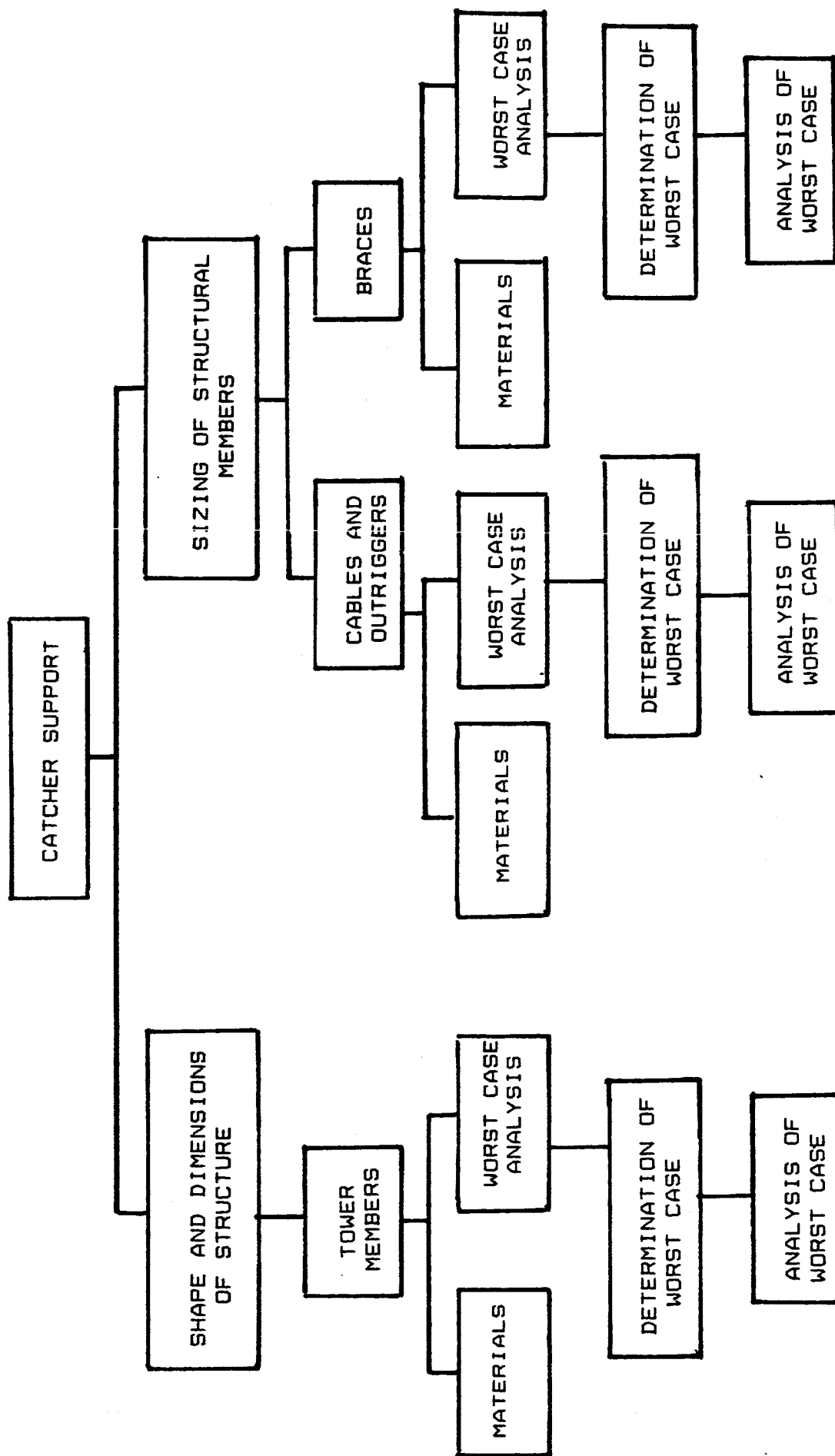


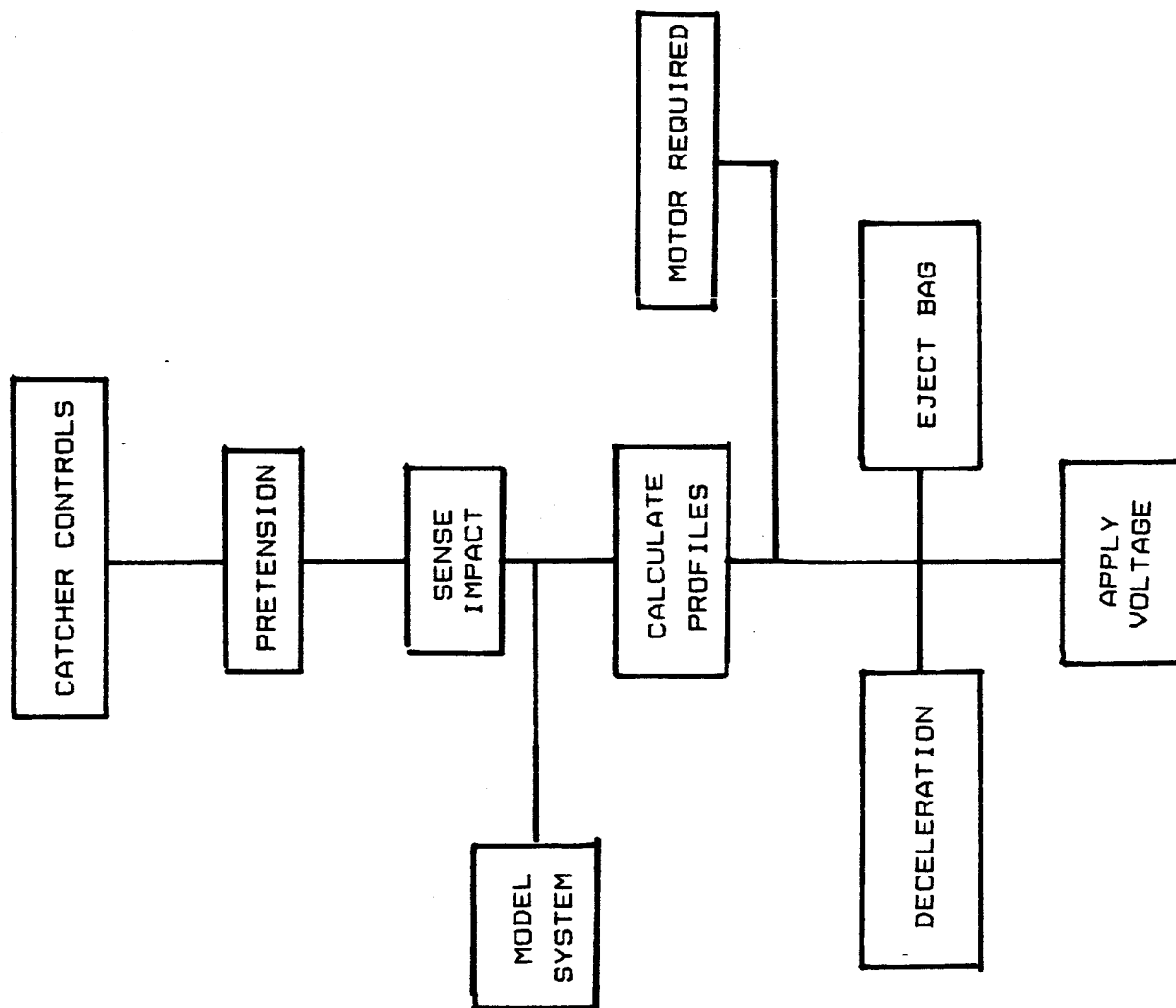


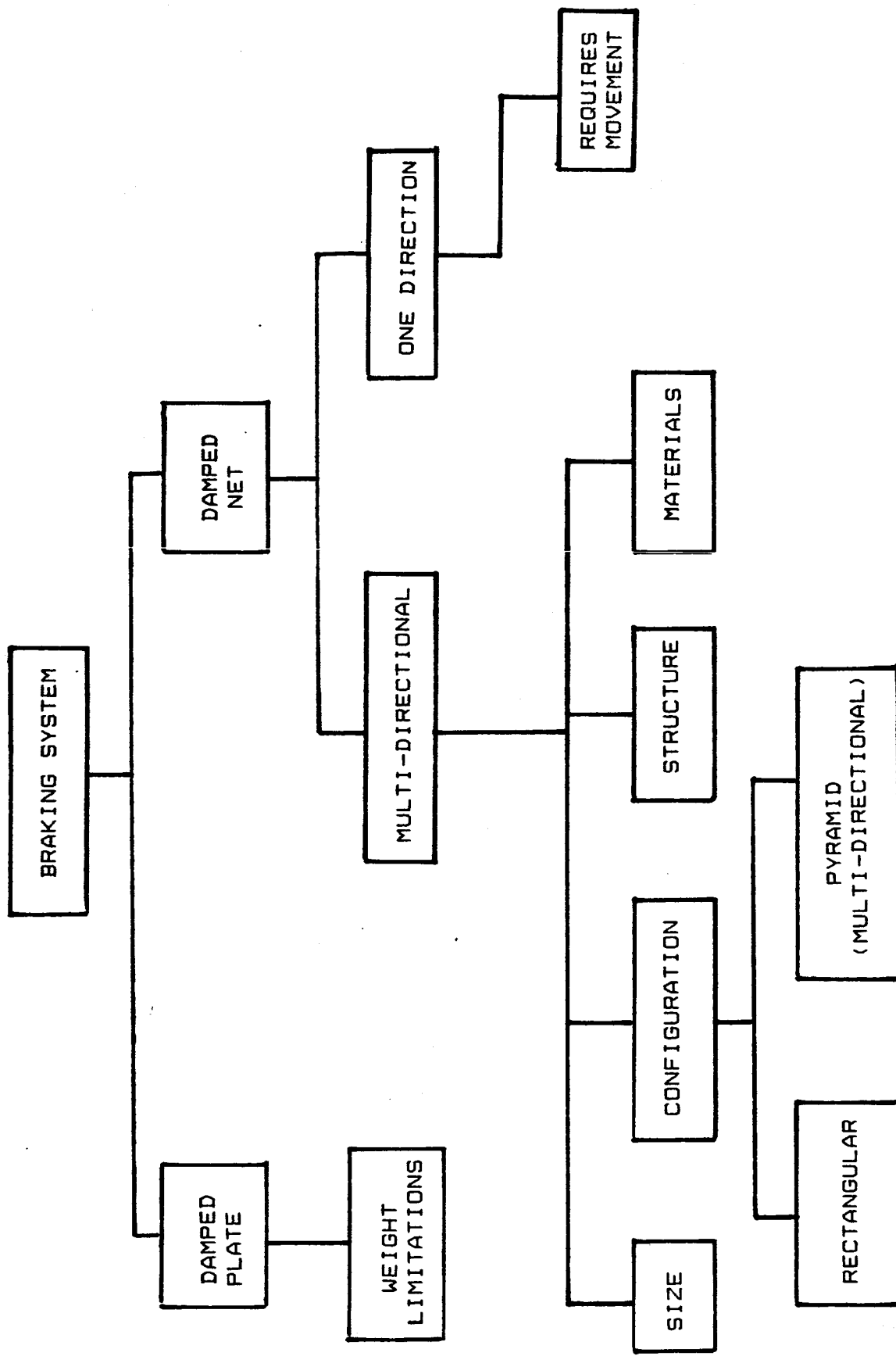












APPENDIX D
DESIGN ALTERNATIVES

DESIGN ALTERNATIVES

I. Launcher Alternatives

A. Vertical Launcher

This method is similar to a water wheel or a ferris wheel. The outer circle has a hook of some sort to catch the bags at the lowermost point of the cycle. Then the motor accelerates the wheel as the bag is lifted along the circumference path and releases the bag at the correct point necessary for the ideal velocity and angle of launch.

The advantages of this method are twofold. One is that it combines the loading and the throwing procedures into one. The second advantage is that after release of the sandbag, the motor may be released as momentum will carry the hook back down to the lowermost position (initial position) and prepare for another launch cycle.

One possible problem is that the wheel would have to accelerate as it turned. This may be difficult for the motor. A possible solution would be to offset the motor with a connecting arm from the motor to an off-center position on the disk, thus causing the disk's rotation to be elliptical. This would deliver more speed at one point in the cycle while still requiring a constant motor torque.

B. Linear Induction Motor

Linear induction motors are being researched internationally and have had some success in applications such as high speed trains and automobile crash testers. The navy is investigating its application as an aircraft catapult on aircraft carriers. It has the advantage that it can develop a high torque, being a DC machine, and can develop high velocities and accelerations. It is also compact and lightweight. Furthermore by a reversal of polarity, the motor will exhibit dynamic braking in which forward motion along the linear track will be brought to a stop while electricity is pumped back into the track for the next start-up.

The lunar catapult would utilize a linear induction motor by attaching the sandbag holder to its slider. Then the motor would be started and would accelerate along its linear path until it reached a point where it would release the sandbag. After it released the sandbag, the polarity would be reversed and the catapult would break itself. The advantage would then be that the slider would just have to

be repositioned at the start of its track to prepare for the next launch. The repositioning would require a minimum amount of energy.

The linear induction motor may well be a feasible alternative in the next ten years if research on the subject continues to increase. Furthermore, not enough practical design theory or experience data exists at this time to safely recommend its application in the lunar catapult.

C. Rail Gun Alternative

An electromagnetic launcher was considered. The idea was based on $j \times B = F$ (electric current crossed with magnetic field equals Force). Many patents were looked up and books were searched, but nothing else could be realistically counted on. All work done thus far has been theoretical. However, the idea appears very good and efficient. Rail guns are currently being researched for Kinetic Energy Kill Vehicles for the Strategic Defense Initiative. This method deserves further consideration but is currently beyond our design scope. See accompanying information.

D. Solenoids

Solenoids were also considered as a possible means of launching the sandbags. However, unpredictability is a major problem. Large forces are generated but specific forces appear unpredictable. Also, current solenoid actuators have a maximum stroke of about 12-15 inches (rather short for our purposes). Although interesting, we ultimately rejected this method of launch.

E. Syncro-Servo Motor

The group considered using a synchro-servo type motor to launch the sandbags arm with a holder would be attached to the motor. The sandbag would be launched due to the difference in the rotor and the stator angles. The resulting torque would propel the arm and the sandbag forward at the angle at which the stator and the rotor are aligned. The movement would be damped and the sandbag would be released.

This design is basically feasible for launching sandbags, but has two inherent faults. First, the use of the arm and motor damping resulted in a complicated aiming system. This system would be inaccurate because of inertia and electrical fluctuation. Second and most important, this

system required an unreasonable amount of power due to the short time period of launching involved.

F. Airbags or Air Springs

Another system that was considered was an air spring system. This system would operate within a linear tube. Basically, the system was comprised of an inflated bladder within the tube which would be compressed to provide the force to launch the sandbag.

Forces large enough to launch the sandbag 300 meters are obtainable but the resulting pressure within the bladder is extremely high. In the hard vacuum of space, this pressure would be a problem. Sealing the bladder effectively without air loss would be very difficult if not impossible. Also the air bag may be susceptible to small pin holes which would result in the air leaking out. For the above reasons, we decided to eliminate the air spring from our design proposals.

II. CATCHER ALTERNATIVES

A. Flat Platform

The flat platform set at an angle of 45 degrees was considered as a catching device for the sandbags. The platform would have a soft, impact absorbing surface as well as being mounted to a structure by a damping shock absorber and compression spring. When the sandbag hit the platform, the platform would be depressed back and during this process absorb the energy of the sandbag. The bag would then slide down the platform into a pile at the base of the structure. The problem that arose from this design proposal was the size of the structure, the weight, and the problem of positioning the catcher relative to where the launcher was located. After thorough consideration, the group decided to reject this proposal.

B. Catcher Net

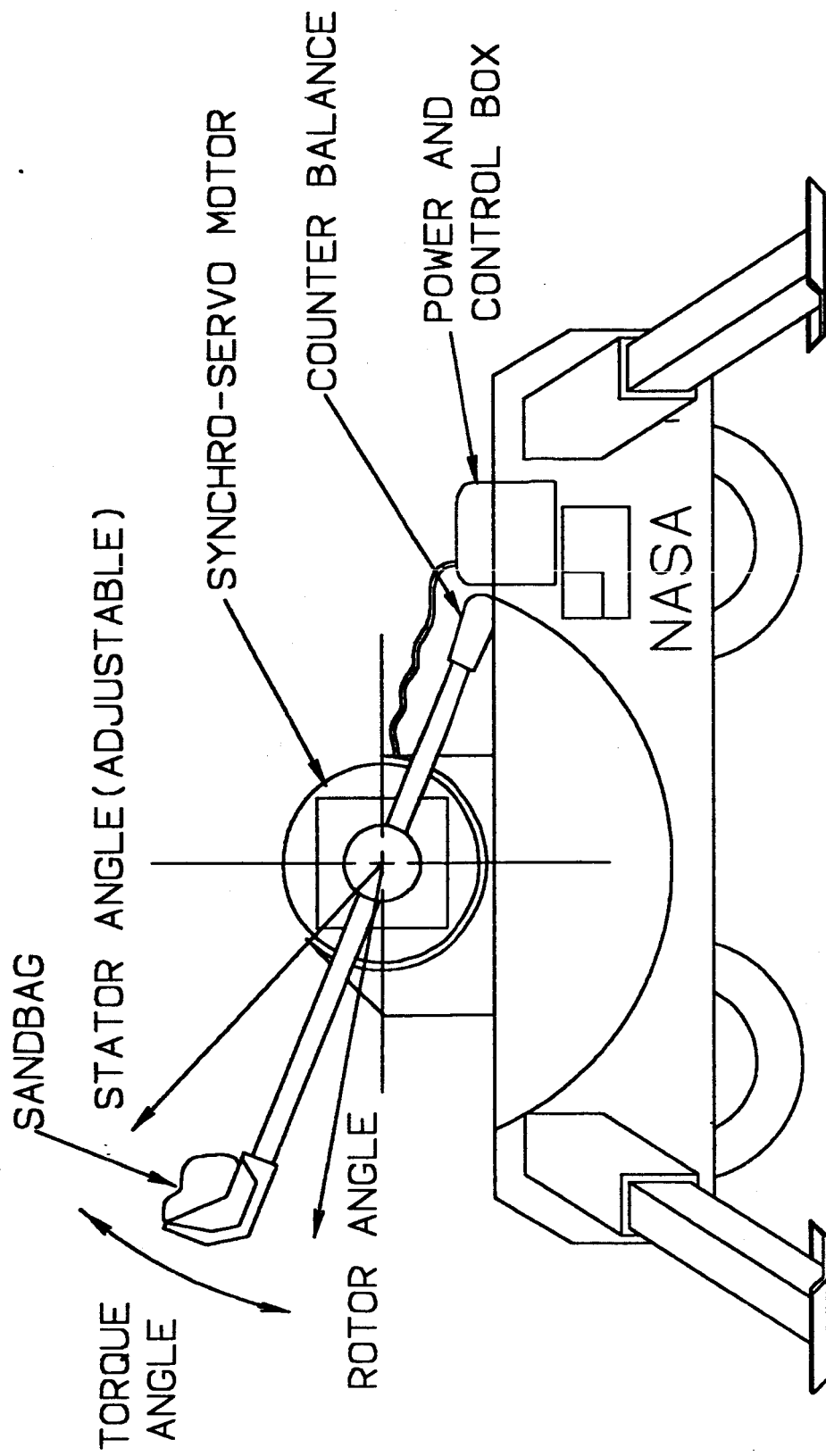
This design proposal was very similar to the type arresting nets used on the runways of today airports. The basic design would be a net stretched between two poles which are in turn connected to a brake at each pole. The sandbag would hit the net and depress it backwards causing the cable on the arresting brakes to be drawn outwards. The brakes would control the rate at which the cables would be

drawn outwards thus slowing the sandbag. The problem with this design is the possibility of the net snagging on impact or rewinding, and the problem of constantly having to align the catcher relative to where the launcher is operating.

ANGULAR LAUNCH METHOD

POWER SUPPLIES

- SYNCHRO - MOTOR
- TORSION SPRING
- FLY WHEEL / MOTOR

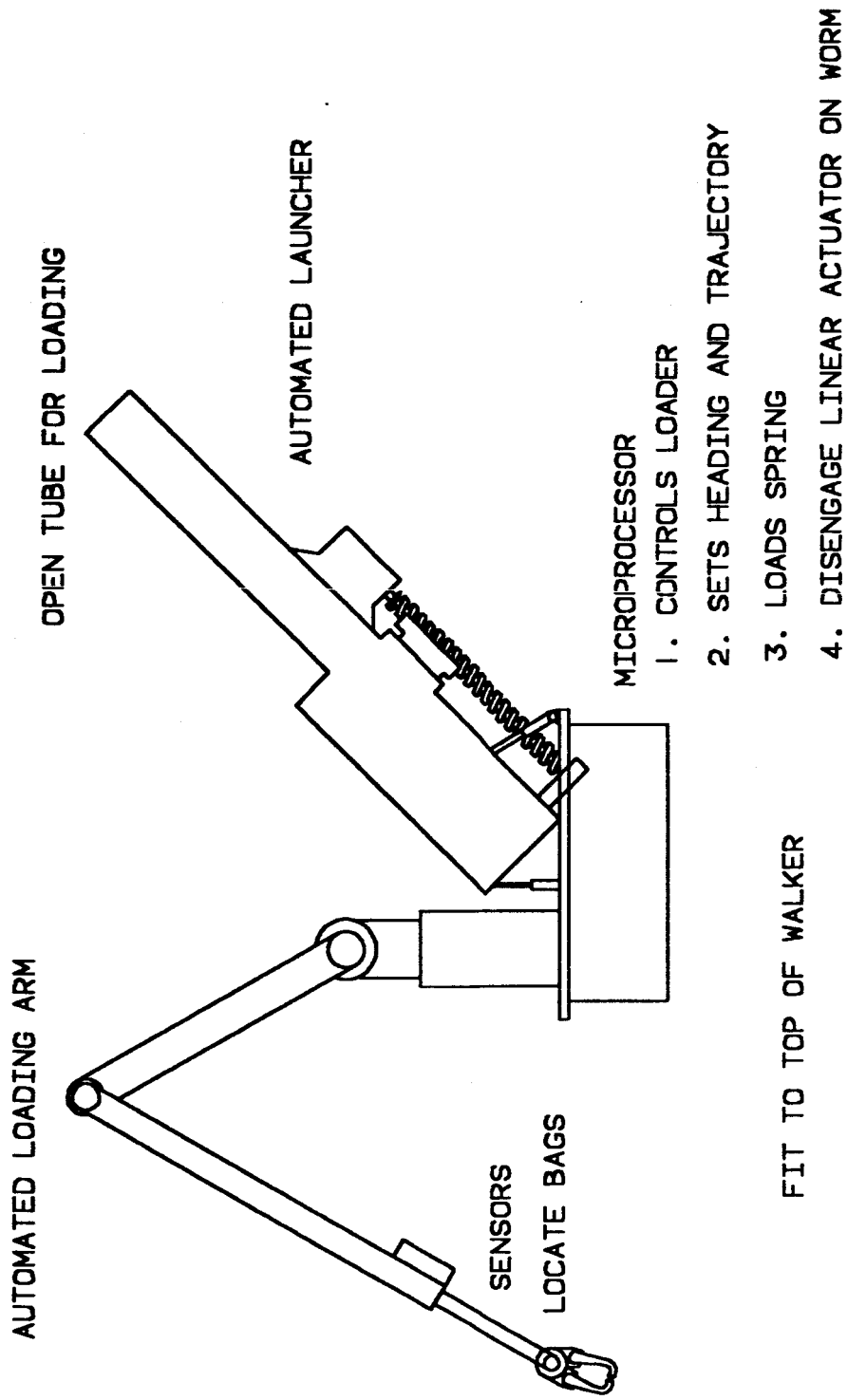


RADIAL LAUNCHER

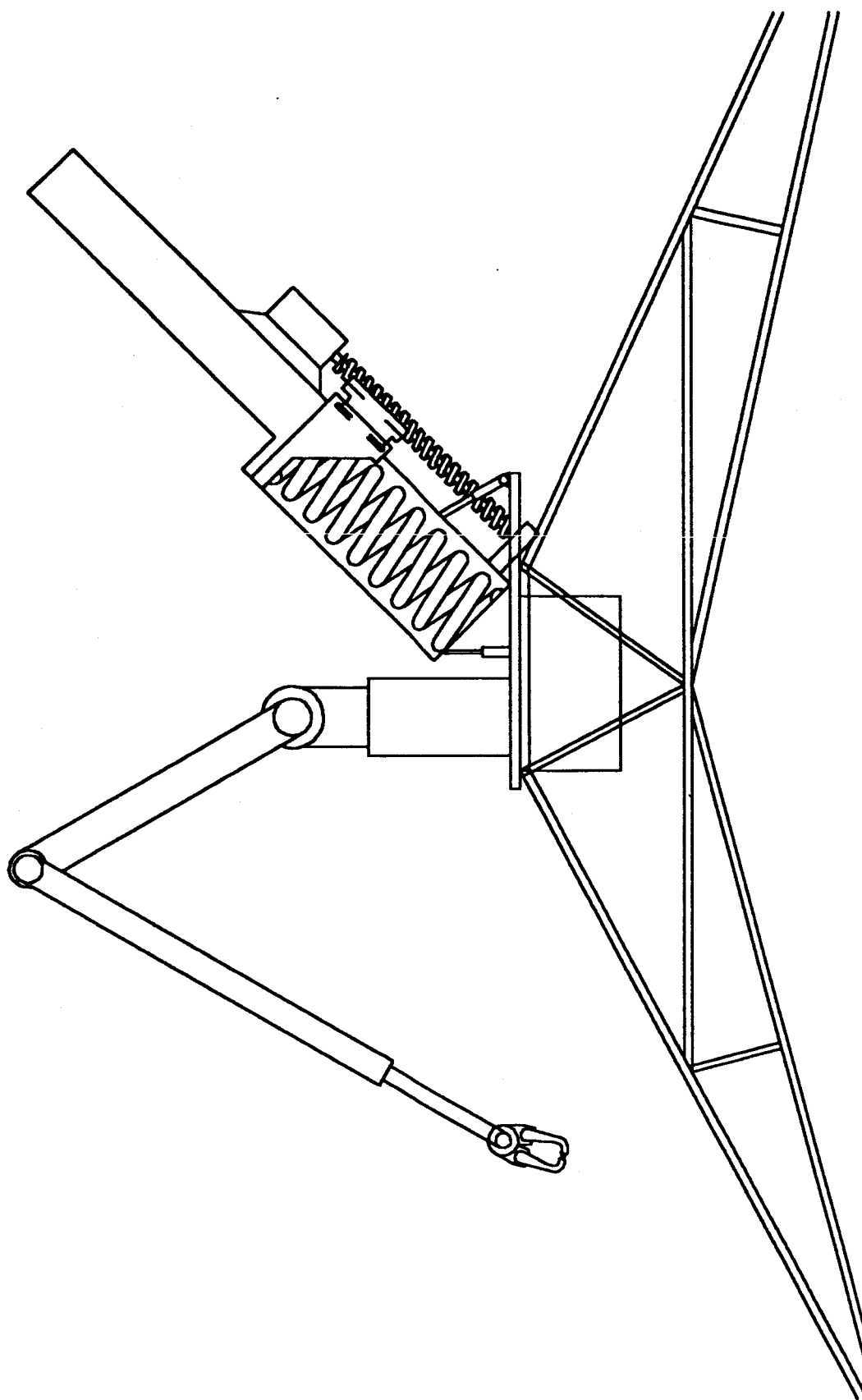
LINEAR LAUNCH METHOD

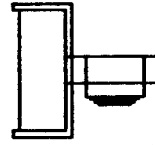
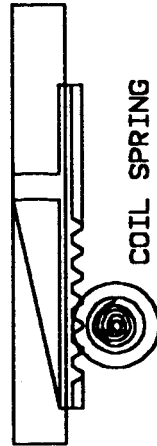
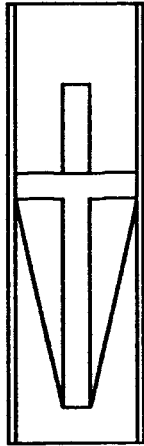
POWER SUPPLIES

- RAIL GUN
- SOLENOID
- MECHANICAL SPRING
- FLUID SPRING



LINEAR LAUNCHER





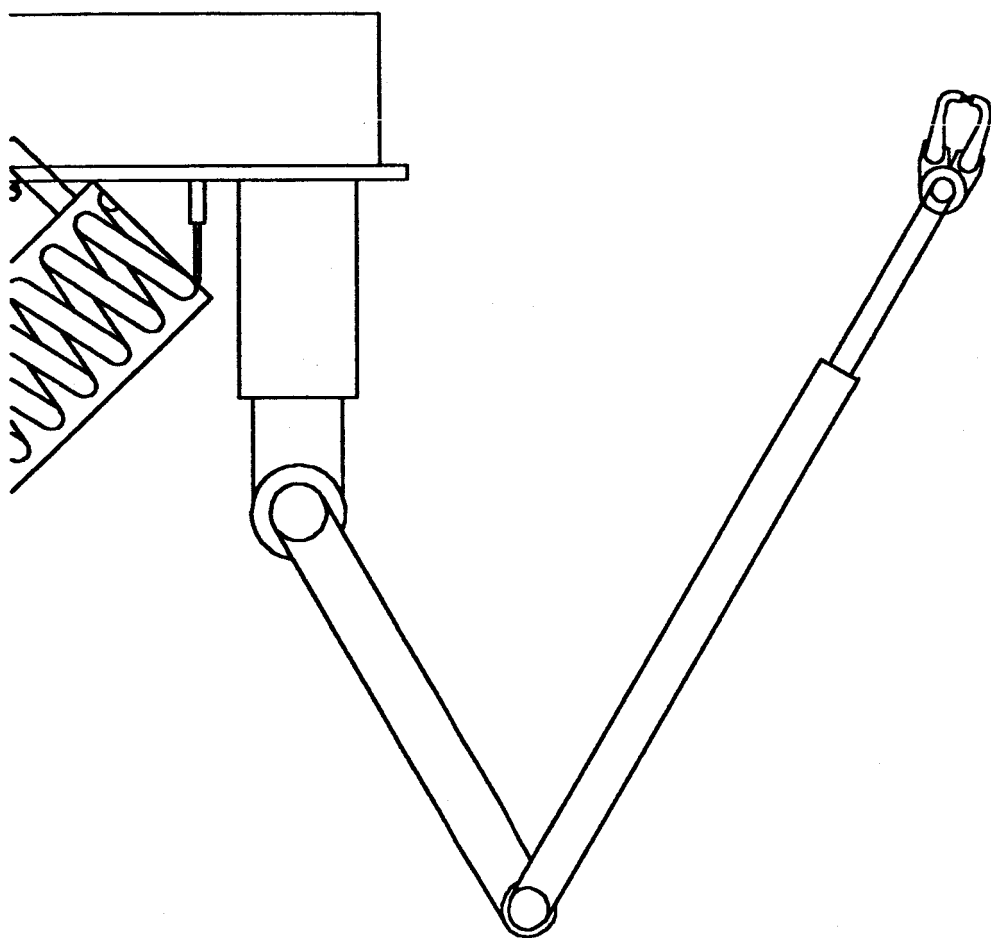
GEORGIA TECH
COLLEGE OF ENGINEERING

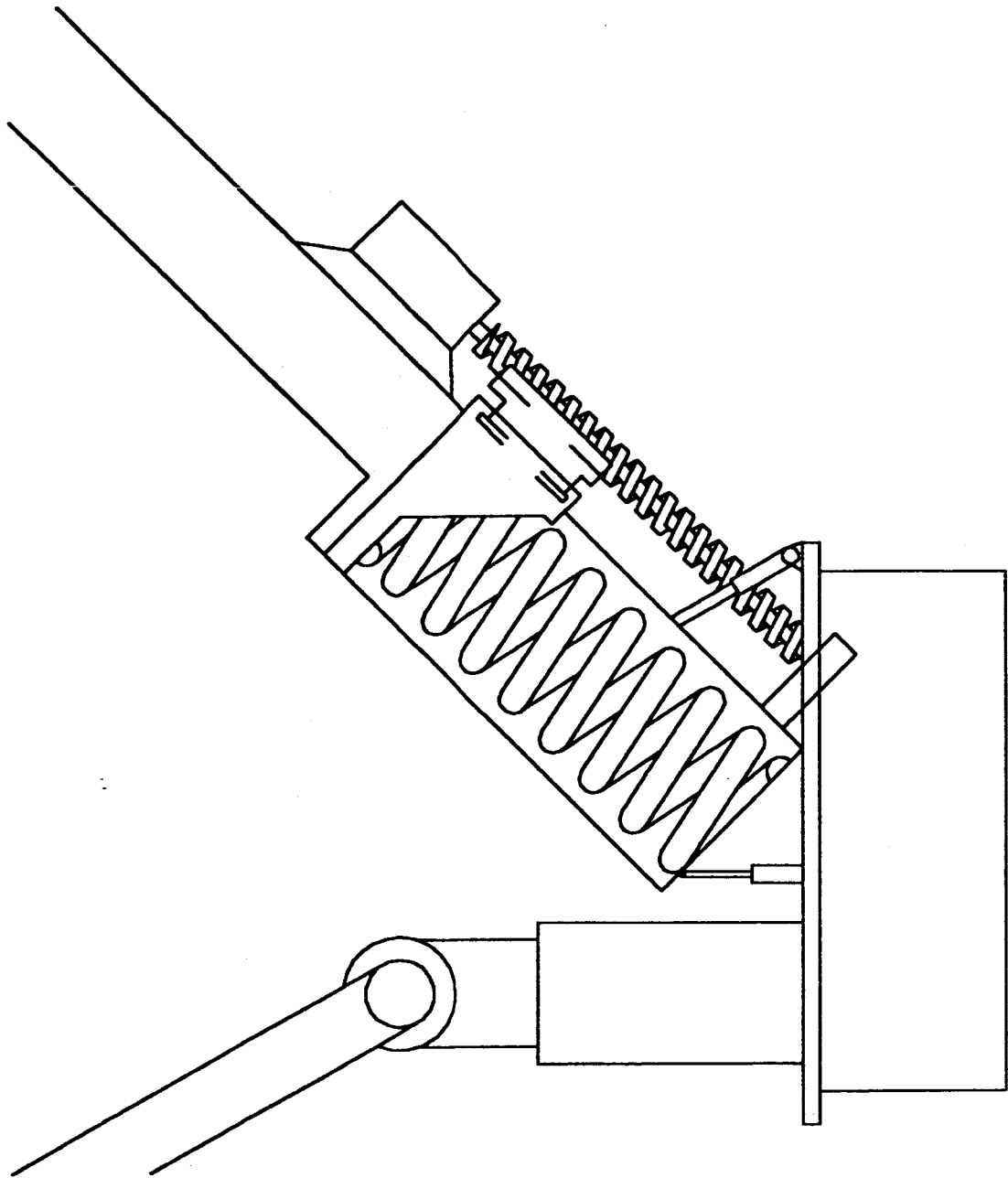
TITLE: TORSION SPRING

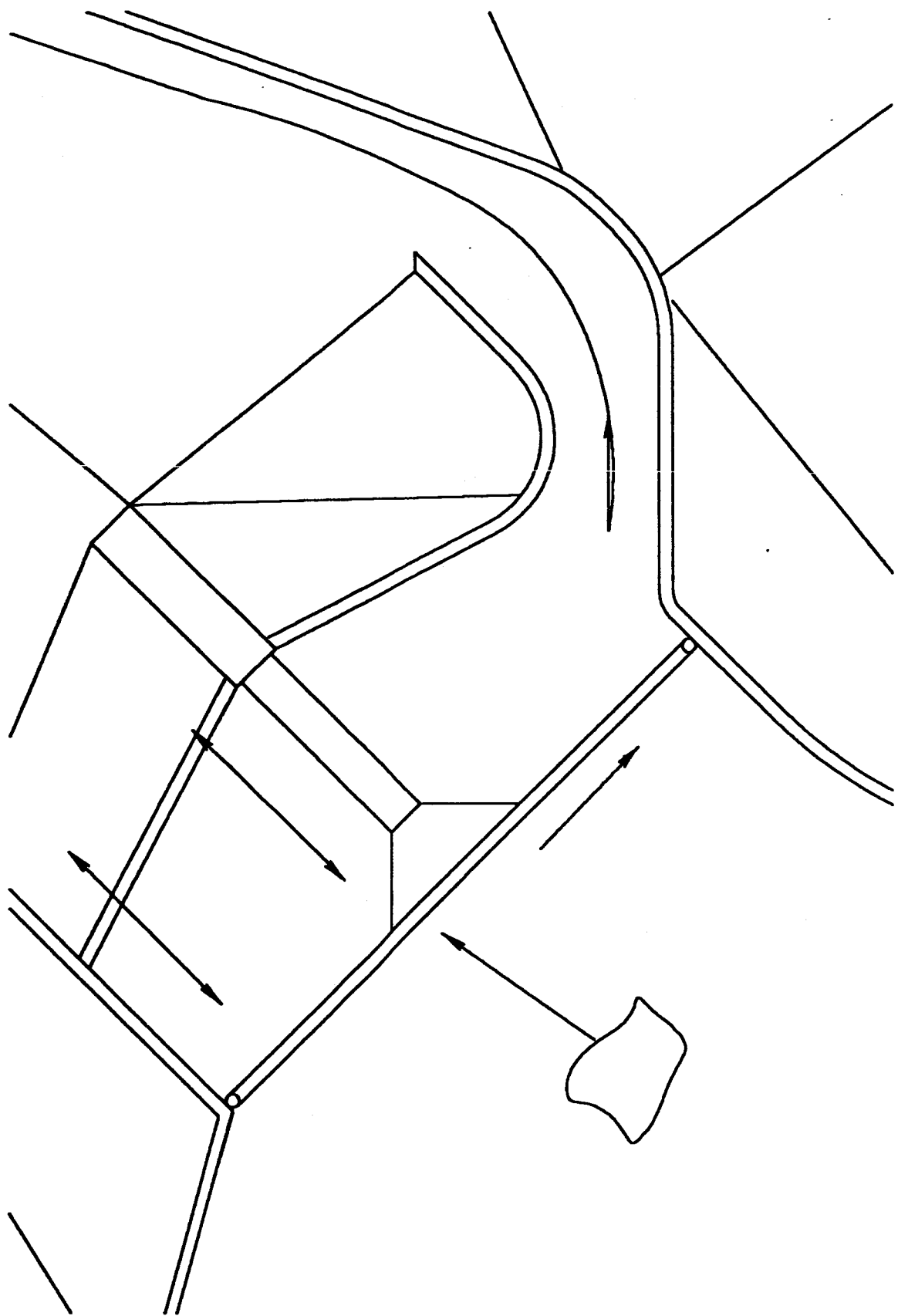
DESIGN: GROUP 2 DATE 5/7/87

CHECK: DATE

DRWG NO.







APPENDIX E
WEEKLY PROGRESSES REPORTS

Weekly Progress Report No. 1

Sand Bag Catapult

Group No. 2

This week we decided to concentrate on the design of the catapult. Later we will use the parameters of the catapult to design the catching mechanism for the sand bags. We will also concern ourselves with the retrieving of filled sand bags for projecting at a later time.

In our discussion of the catapult design, we narrowed the scope of our design to some type of inclined thruster instead of a traditional type catapult with a moving arm. We chose this type of projection in order to reduce the number of moving parts and to simplify the design.

We discussed many types of inclined thruster mechanisms. Using the inclined thruster idea, we looked at various energy conversion methods for propelling the sand bags. Among these were pneumatic, mechanical spring, solenoid, electric servo motor, and electrical rail gun. We discussed the basic advantages and disadvantages of each system. We concluded that the solenoid approach could be promising because of its simplicity and its ability to be electrically damped after tossing the sand bag. We decided that additional information is needed before arriving at the most appropriate energy conversion method.

Assignments were made to group members to obtain this additional information. We will investigate acceptable materials for the design, solenoids, available power on the lunar surface from fuel cells, and lunar surface data. We will also make some basic calculations to determine the feasibility of the solenoid method of projection.

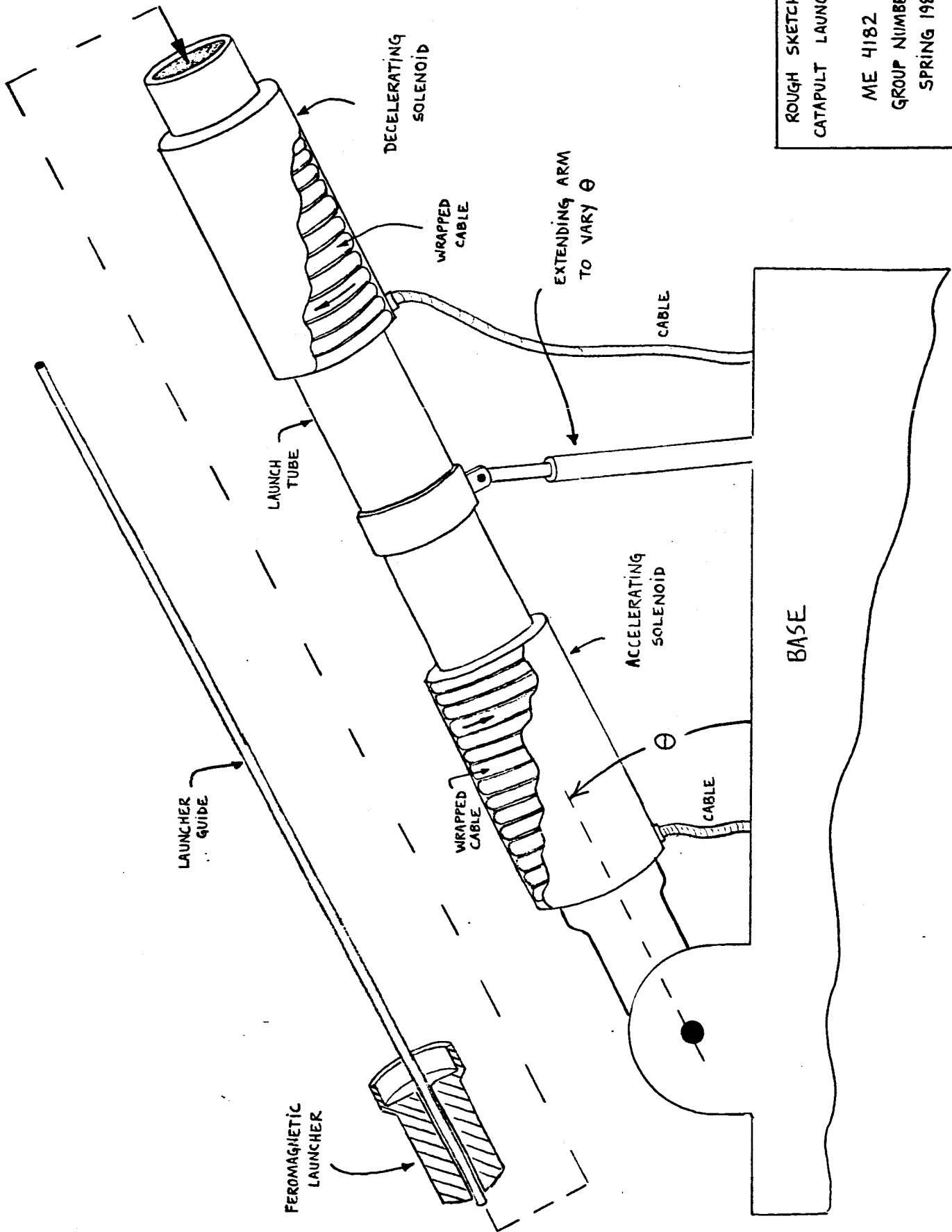
A preliminary sketch of our system is attached. The system uses a tube and plunger type assembly for aiming and projecting the sand bags. This sketch is a schematic view of our apparatus, which can be used for several of the energy conversion methods mentioned above.

ROUGH SKETCH OF
CATAPULT LAUNCH UNIT

ME 4182

GROUP NUMBER 2

SPRING 1987



Weekly Progress Report No. 2

Sand Bag Transport

Group No. 2

This week we continued to obtain the information necessary to narrow our design options down. We have decided not to limit ourselves to a specific method of sand bag transporting this early in the design process; we will instead contemplate several different methods. We will choose between these methods when enough information has been gathered to make an intelligent choice. With this goal in mind, assignments to research specific areas were made to the group members. These areas included traditional catapults, mechanical springs, solenoids, and railguns. We specifically want to look at lunar adaptability and design feasibility while keeping the performance criteria and constraints in mind. Resources for these assignments included trade journals, patents, and NASA material. research is progressing satisfactorily.

We progressed in other areas as well. The problem statement was finalized and is ready to be presented. Performance related calculations were made involving the physics of the sand bag trajectory. Additional research is to be conducted in various areas. For example, we will examine the maximum range of the sand bag transporter by calculating the radius of the circle needed in order to obtain the required square footage of lunar soil.

One noteworthy accomplishment was agreeing with the sand bag group on some standards for sand bag size and weight. We agreed on the following parameters: a volume of 2 cubic feet and an approximate mass of 113 kg. The sand bag group will make arrangements for each bag to be very close to this mass. Exact tolerances were not available at this meeting. If the sand bags have very small tolerances, we may not need to weigh each bag and correct for its variable mass. We also agreed that the sand bag group would stack the bags instead of laying them out as they go. This alleviates some movement problems for us. The sand bag group also mentioned that the sand bags would be bracketed for ease of handling. We will keep this in mind as we examine our own bag handling system.

A LAUNCH AND RECOVERY SYSTEM FOR USE IN
TRANSPORTING SANDBAGS ON THE LUNAR SURFACE

ME 4182 Mechanical Design Engineering

Mark Madler
Don Griffin
Jeff Wingard
Dean O'Donald
Terry O'Bannon
Phil Johnson
Ken Nicholas
David Corbin

ME 4182
Group #2
Dr. Brazell
April 9, 1987

ME 4182

GROUP #2

APRIL 10, 1987

PROBLEM STATEMENT:

Soil samples on the lunar surface need to be transported efficiently from one site to another specified site. The proposed means of transporting these samples is a catapult/catcher type system. The following assumptions will be made in this project:

- 1) A crane will be available to load the samples in the catapult and unload the samples from the catcher.
- 2) The soil samples will be in 2 cubic foot containers.
- 3) The catapult and catcher will be placed on the surface by a lunar walker.
- 4) Energy put on the sample at launch will not be dissipated during launch, due to lack of atmosphere.
- 5) Maximum desired distance for catapulting samples will be 800 meters.

ME 4182
GROUP #2
APRIL 17, 1987

PROBLEM STATEMENT:

I. INTRODUCTION

The current design for a lunar base calls for cylindrical modules to be partially buried in the lunar soil and then insulated from heat and radiation by a covering of lunar soil. This soil could be loosely piled, formed into bricks, or collected into sandbags. Because of the tremendous energy cost of excavating into the hard lunar surface, only the loose topsoil would be collected and bagged (assuming sandbags are used for insulation). This would necessitate going some distance from the modules to collect soil. Therefore the distance the bags would have to be transported from where they are made to the modules could be quite large.

Since the moon has essentially no atmosphere and only one-sixth of the earth's gravity, throwing and catching the sandbags could prove to be an efficient mode of transportation. Assuming sandbags are used to insulate the modules and throwing is used for transportation, we shall determine what type of throwing and catching system would be best for use on the moon.

II. PERFORMANCE CRITERIA

The catapult/catcher system will be designed to meet the following performance criteria:

A. OPERATING PARAMETERS

1. Throwing Distance: The catapult should operate at a radial distance from the module that will provide sufficient sand volume to cover the module surface with sandbags.
2. Sandbag Weight: The catapult will have a maximum and minimum weight sandbag that it will be able to throw.
3. Rate of Launching: An efficient rate will be determined based on the final design. It must be fast enough to make this concept of sandbag transportation a better choice than alternative concepts.
4. Reliability: Due to its location and accessibility, the system should work correctly for a large number of repeated transports without major maintenance. The system must complete a continued process, not a one repetition process.

5. Launch Positions: Since the catapult/catcher will be roughly placed by the walker, and the moon is not a perfectly flat plate, the system should operate from a maximum range of launch positions.

B. COMPLETELY AUTOMATED

Due to the limited accessibility of the moon and the difficulty of working in its environment, this catapult/catcher system could ideally be completely automated. This automation would enable the system to be operated from within the modules, or remotely from an orbiting spacecraft or even Earth. The automation would mainly be in terms of quality control, as applied to the following two processes:

1. Weight: The catapult/catcher would automatically sense different weight sandbags and compensate throwing strength accordingly.
2. Distance: The system would be able to adjust to different target distances automatically.

III. CONSTRAINTS

The following constraints on our design of the catapult/catcher system must be considered:

A. WEIGHT

The approximate cost to transport material and equipment from Earth to the moon is estimated to be \$15,000 / pound. This high cost of transportation puts important limitations on our design from a weight standpoint. The need to keep the catapult/catcher system lightweight must be adhered to during all phases of the design process.

B. ENVIRONMENT

The environment on the surface of the moon is much different than that of Earth. Some of the important environmental conditions which will limit our design are as follows: there is effectively no atmosphere and therefore a vacuum exists, the temperature ranges from approximately 200 F to -200 F, there is considerable solar radiation, and incoming meteor showers often hit the surface. Each of these conditions will need to be considered when designing the catapult/catcher.

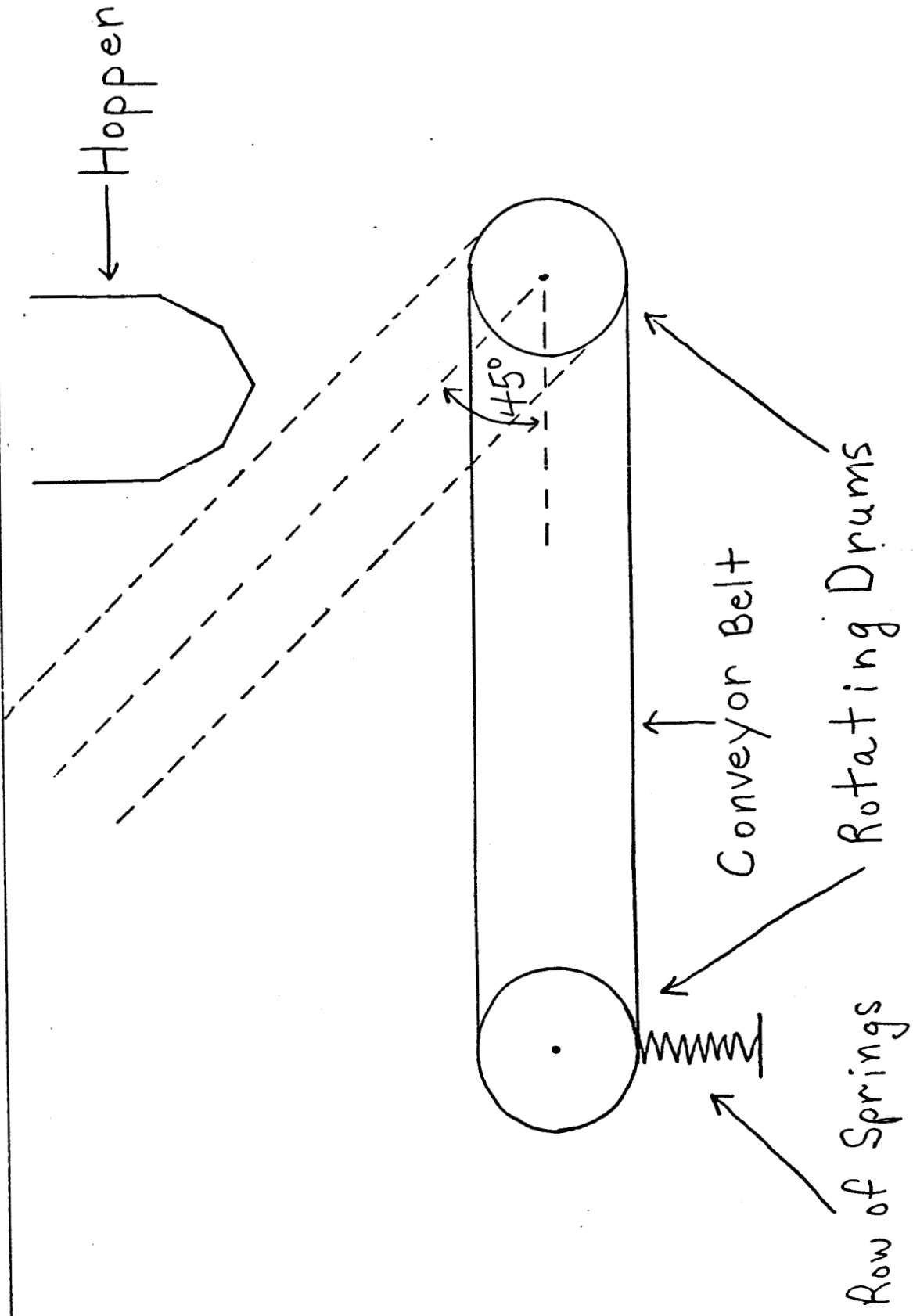
C. TRANSPORT AND PLACEMENT ON THE MOON

The catapult itself must be designed such that it can be transported and placed at each location by a lunar walker which has been previously

designed.

D. ENERGY SOURCES

The energy sources available for use on the moon are limited. The energy requirements of both the catapult and the catcher system must be designed around sources which are feasible and available.



PROGRESS REPORT 3

ME 4182

TO: MR. BRAZELL

FM: GROUP 2

Group 2 met twice this week and accomplished the following work as related to the catapult project. We listed all our current alternatives for the catapult system and did some brainstorming that produced several more alternatives, including looking at the problem from the opposite perspective and possibly pulling the bags in instead of throwing them and catching them. Designs were designated into two main categories: arm through an angle type and thruster type linear launchers. Energy calculations were then made to compare these two types and choose the best one to focus on as we narrow down our design alternatives.

INDIVIDUAL ASSIGNMENTS:

DEAN O'DONALD: Revised the energy calculation program to include kinetic energy, further throwing distances and to calculate launch time.

MARK MADLER: Further research on fuel cells, especially pertaining to recharge life, total life, power generated and cost.

KEN NICHOLAS: Further patent research in electromagnetics, including induction, repulsion and DC rail guns.

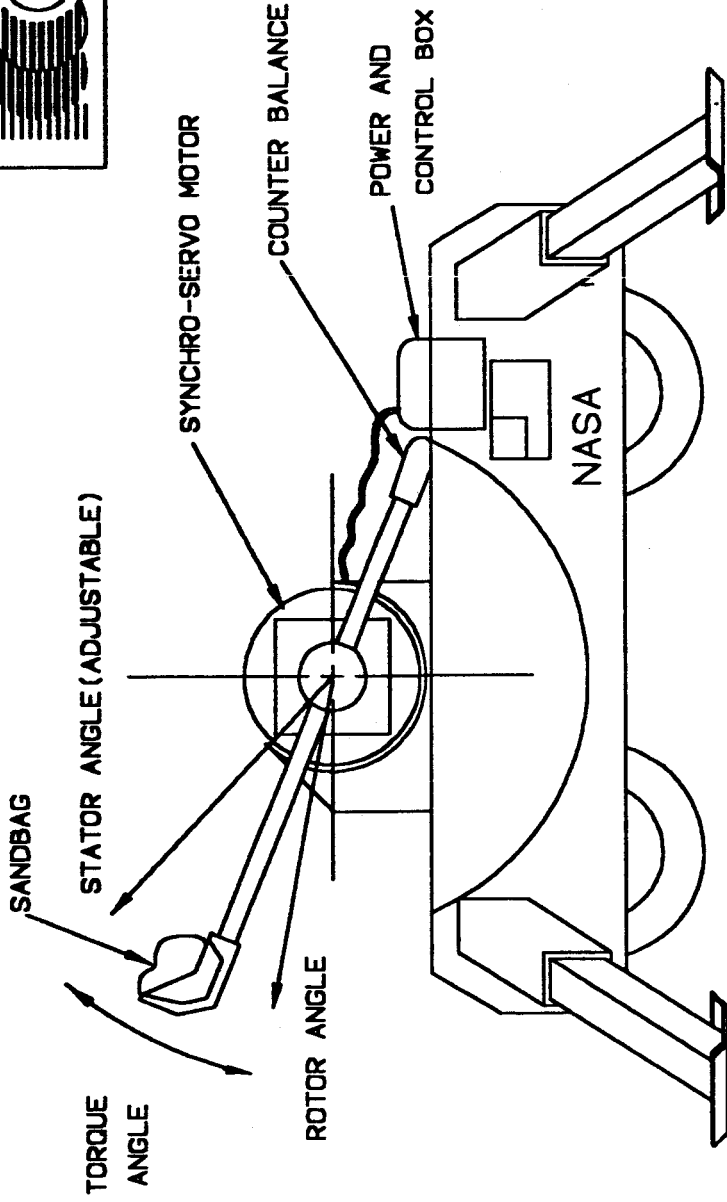
DAVE CORBIN: Further patent research in electrically actuated projectile strikers, as well as some catcher systems like the basketball returner.

TERRY O'BANNON: Calculation of energy equations pertaining to rotary arm type launchers.

JEFF WINGARD: Energy calculations for linear plunger type catapults and comparing energy demands of several designs.

DON GRIFFIN: Researched the synchro-servo motor system for its possible application as a launcher.

PHIL JOHNSON: Worked with CADAM system to make this week's drawings and increase his knowledge of the CADAM system.



CATAPULT PROPOSAL I

GEORGIA TECH
COLLEGE OF ENGINEERING
TITLE: ME 4182 GROUP 2
DESIGN: CATAPULT I DATE 4/23/87
CHECK: DATE
DRWG NO. ONE

Date: April 31, 1987
To: Mr. J. W. Brazell
From: Group Number Two
Subject: Progress Report Number Four

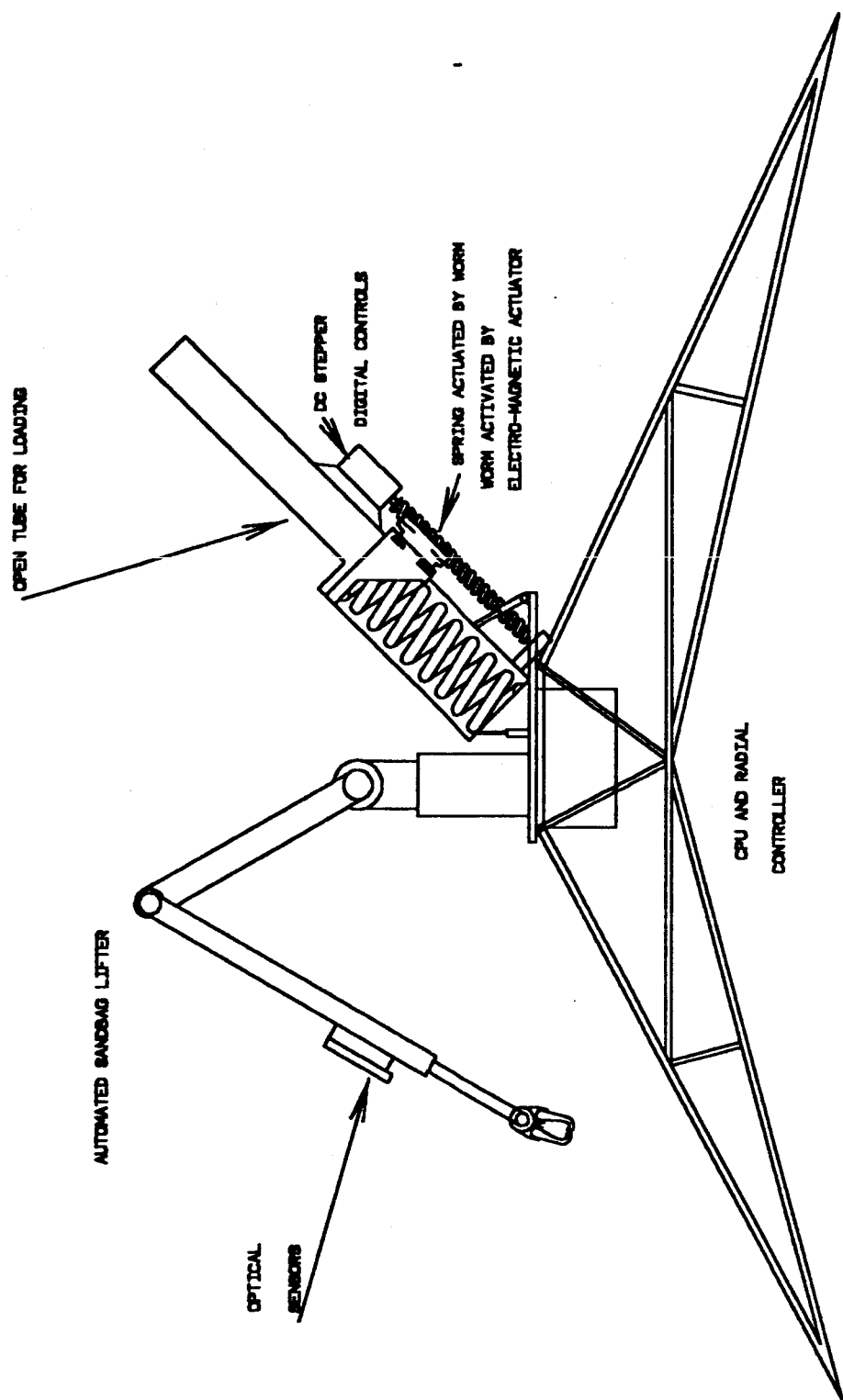
We made progress in several areas this week. We have decided to narrow the scope of are design to the inclined thruster and plunger-tube systems that we have examined. We reached the conclusion that this type of design would be far easier to control. We evaluated the energy requirements of an electrically actuated linear device and found the requirements to be very large.

We feel that a more feasible and practical design would include some type of mechanical spring. The types of springs that we are looking at are helical, leaf, bow, and air or fluid springs. Although we have not finished our research on the air spring, we feel it may be a feasible means of launching the sand bags. In order to fully research these mechanisms, we have decided to use our on-line funds to research them.

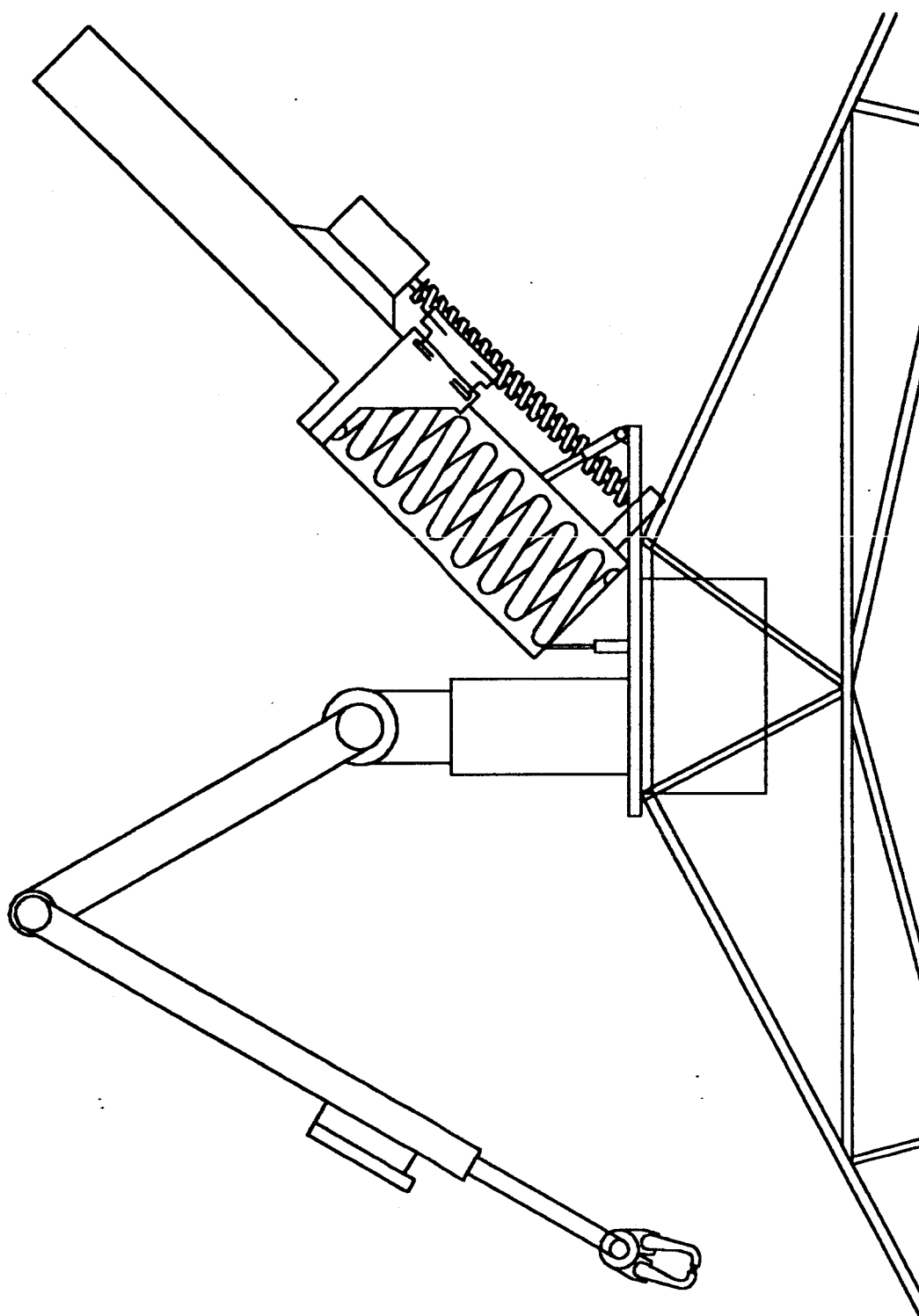
The remainder of our time was spent preparing for the oral presentation given on Thursday.

The individuals in our group accomplished the following:

- Dave - Researched leaf and bow springs.
- Jeff - Prepared transparencies for presentation and prepared project report outline.
- Mark - Prepared transparencies and looked into air springs.
- Terry - Prepared and gave oral presentation to the class.
- Dean - Prepared report outline.
- Ken - Calculated energy needs of the electrical systems to determine feasibility of design.
- Phil - Prepared all drawings for presentation.
- Don - Researched air springs and prepared progress report.



SANDBAG TRANSPORT- AUTOMATIC CATAPULT AND LIFTER



FINAL REPORT OUTLINE

ME 4182
SPRING 1987
GROUP NUMBER 2

- I. Title Page
- II. Illustration
- III. Table of Contents
- IV. Abstract
- V. Body of Report
 - A. Problem Statement
 - 1. Introduction
 - 2. Performance Objections
 - 3. Design Constraints
 - B. System Description and Analysis
 - 1. Loading
 - a. Mechanism Description (Drawings)
 - b. Sensors
 - c. Controls
 - d. Cycle Time
 - e. Materials
 - 2. Launching
 - a. Mechanism Description (Drawings)
 - b. Performance
 - c. Energy and Power Supplies
 - d. Launch Parameters Sensing and Calculating
 - e. Launch Controls
 - f. Materials
 - 3. Catching and Delivery
 - a. Mechanism Description (Drawings)
 - b. Energy Conversion and Storage System
 - c. Final Delivery Location
 - d. Materials
- VI. Conclusions And Recommendations
 - A. Weight And Cost
 - B. Alternatives To Be Considered
 - C. Recommendations For Further Consideration
- VII. Acknowledgements
- VIII. References
- IX. Appendices

DATE: May 8, 1987
TO: Mr. J. W. Brazell
FROM: Group Number Two

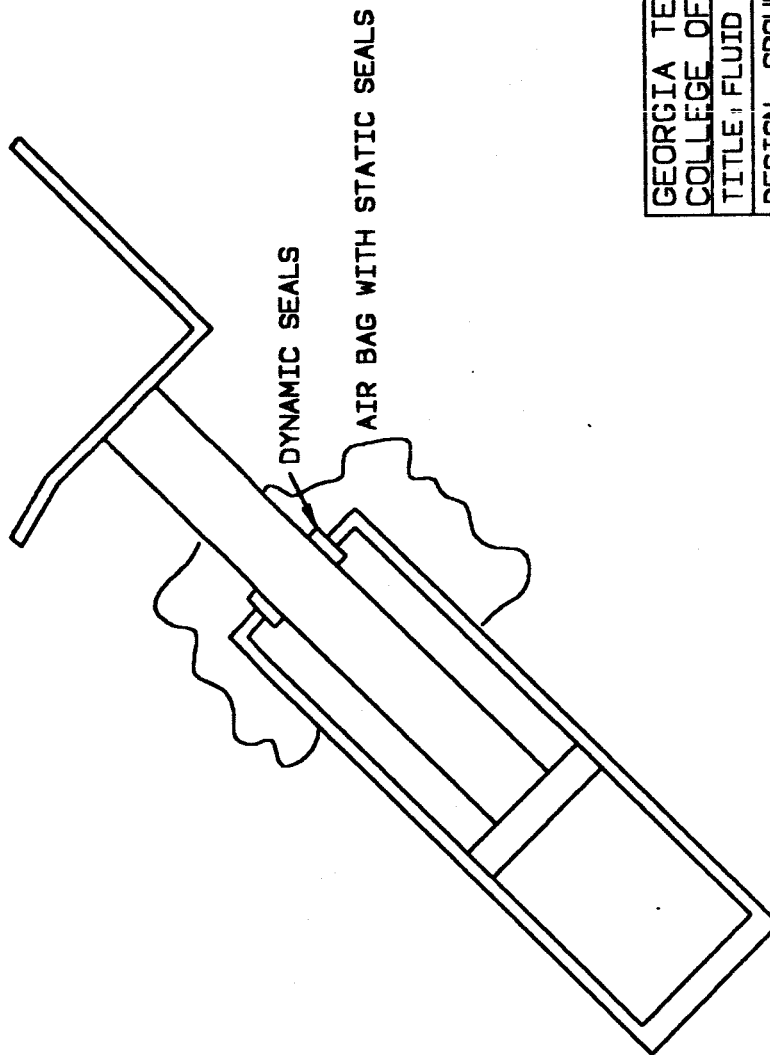
SUBJECT: Weekly Progress Report Number ~~Two~~ 5

This week our group narrowed our design of the launcher to a linear thruster inclined at 45 degrees. Based upon this design, the group broke up into members of two to investigate four different power conversion methods(i.e. launchers). These methods were as follows:

- Compression Spring
- Fluid Spring
- Leaf Spring
- Torsion Spring

The VSMF system in the library along with other available information was used by each group member for his research. Upon completion of all these investigations the entire group met to construct a Decision Matrix to determine the best power conversion method. It became obvious from the decision matrix that the two best methods were compression springs and torsion springs. The group decided to further investigate each of these two methods before making a final decision. The individual accomplishments for this week are as follows:

- Dave: Investigated leaf spring method and worked on computer program to illustrate the design proposals.
- Dean: Investigated leaf spring method with Dave and worked on computer program to illustrate this design proposal. Worked on weekly progress report.
- Terry: Investigated torsion spring method with Jeff.
- Jeff: Investigated torsion spring method with Terry and worked on weekly progress report.
- Mark: Investigated compression spring method with Phil and met with the Librarian for data base search.
- Phil: Investigated compression spring method with Mark and prepared weekly drawings on CADAM.
- Don: Investigated fluid spring method with Ken.
- Ken: Investigated fluid spring method with Don.



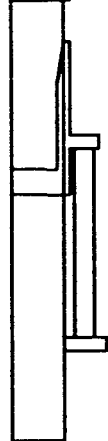
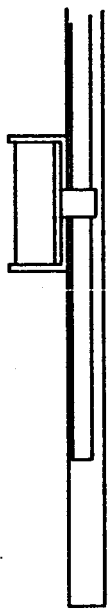
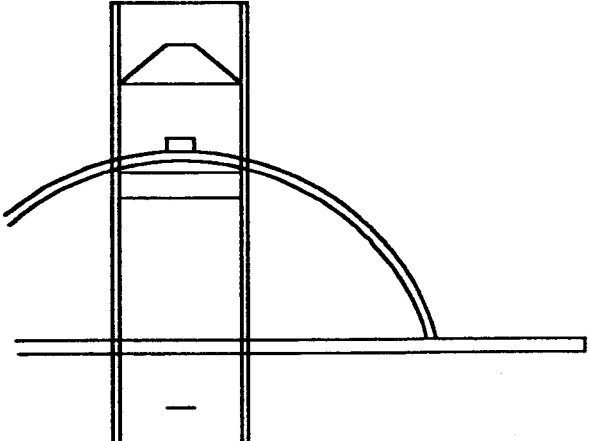
GEORGIA TECH
COLLEGE OF ENGINEERING

TITLE: FLUID SPRING

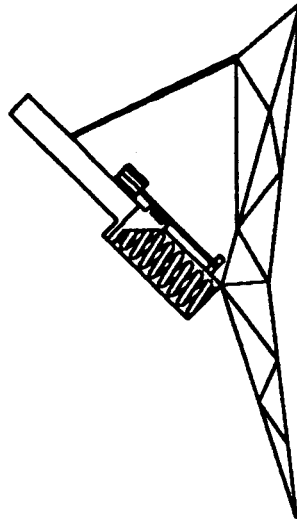
DESIGN: GROUP 2 DATE 5/7/87

CHECK: DATE

DRWG NO.



GEORGIA TECH	
COLLEGE OF ENGINEERING	
TITLE: LEAF SPRING	
DESIGN: GROUP 2	DATE 5/7/87
CHECK:	DATE
DRWG NO.	



GEORGIA TECH
COLLEGE OF ENGINEERING

TITLE: COMP. SPRING

DESIGN: GROUP 2 DATE 5/7/87

CHECK: DATE

DRWG NO.

MEMORANDUM

DATE: May 15, 1987

TO: Mr. J.W. Brazell

FROM: Group #2

SUBJECT: Weekly Report #6

This week the search information was returned from the librarian. The information is currently being evaluated. In the next few days we hope to investigate these new sources. So far the material deals mainly with various types of springs and also fuel cells which we plan to utilize.

During our two major group meetings, we formed subgroups in order to deal with specific design considerations. Each subgroup has the responsibility for investigating their specific topic. Results will be subject to group review. The 4 subgroups are:

1. Catcher
2. Launcher
3. Structures
4. Controls

Dean & Don: We examined aircraft arresters and their applications to the sandbag catcher. A preliminary design was developed which looks very encouraging.

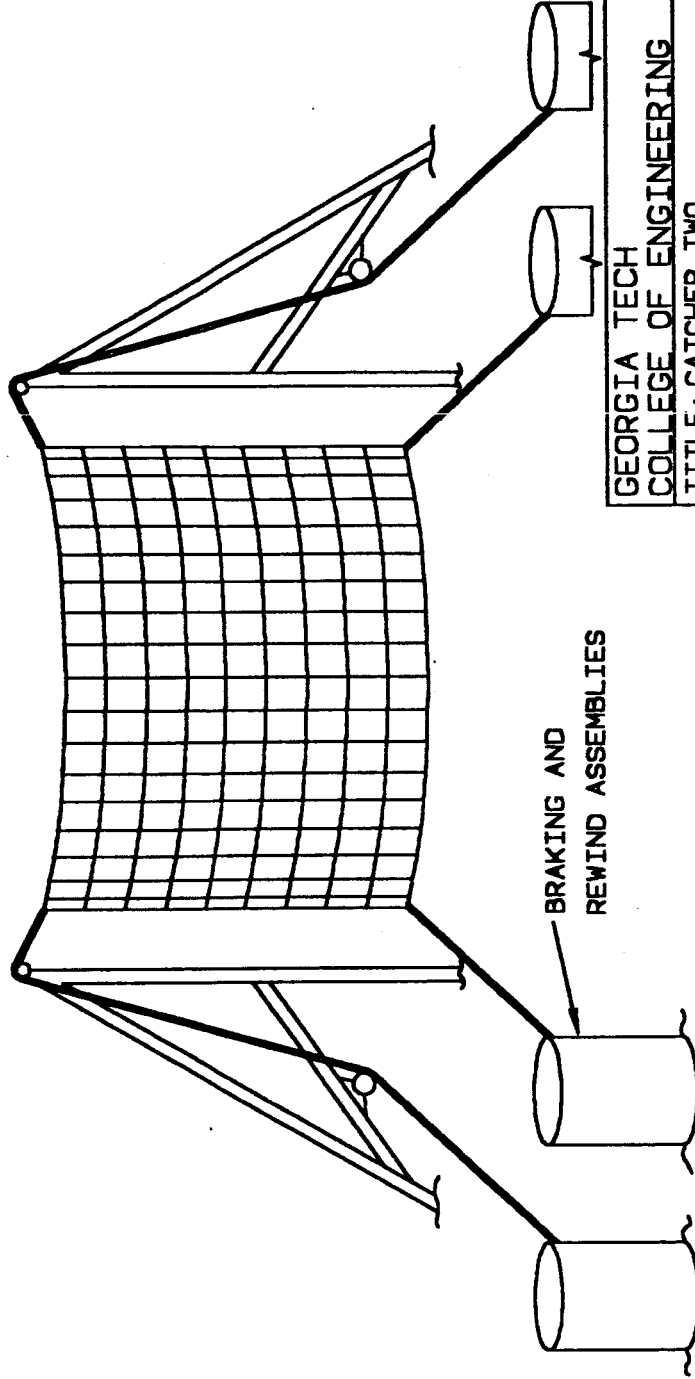
Mark & Jeff: We began to design a launch system using a combination of compression and extension springs. In addition we decided to take a closer look at linear induction motors as an alternative launch system. EE profs will be consulted.

David & Phil: We looked into the support mechanisms for the catapult and catcher. Under consideration is the force the skitter will be able to withstand. Also we are relating the force to the distance of acceleration and deceleration.

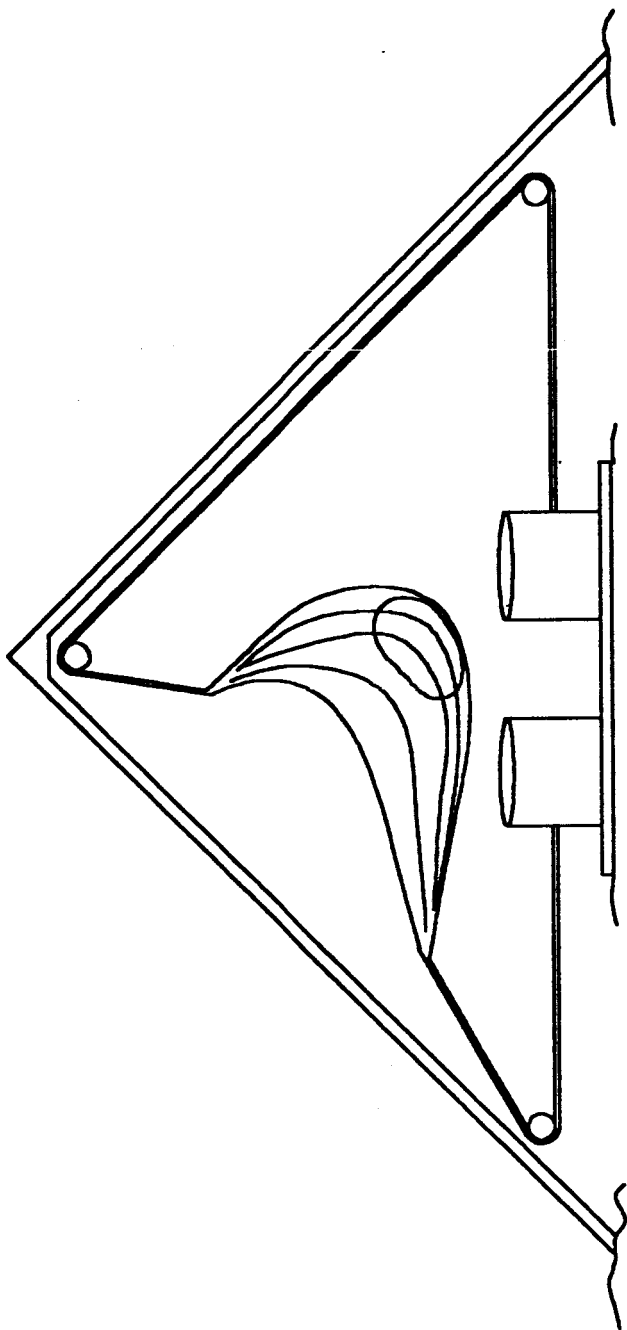
Ken & Terry: We investigated control systems, looking at different parameters to be measured, sensors available, and control schemes. Effort was made to consult with Dr. Jarzinski concerning laser range finders, but he was unavailable.



LUNAR SANDBAG CATCHER



GEORGIA TECH	
COLLEGE OF ENGINEERING	
TITLE: CATCHER TWO	
DESIGN:	DATE:
DON AND DEAN	5/14/87
DRAWING BY: PHIL	



GEORGIA TECH
COLLEGE OF ENGINEERING

TITLE: CATCHER THREE

DESIGN: DEAN & DON

CHECK: DATE 5/14/87

DRAWING BY: PHIL

PROGRESS REPORT 7

ME 4182

TO: MR. BRAZELL

FM: GROUP 2

Group 2 continued working in teams but met as a group several times to compare ideas and progress. Major accomplishments for the week include further design of the catcher system, selection and optimization of a catapult mechanism and initial work on the report rough draft.

TEAM ASSIGNMENTS:

DEAN O'DONALD AND DON GRIFFIN: Designed the catcher system and talked to Dr. Olsen in the Textile department about how to design the fabric for the catcher.

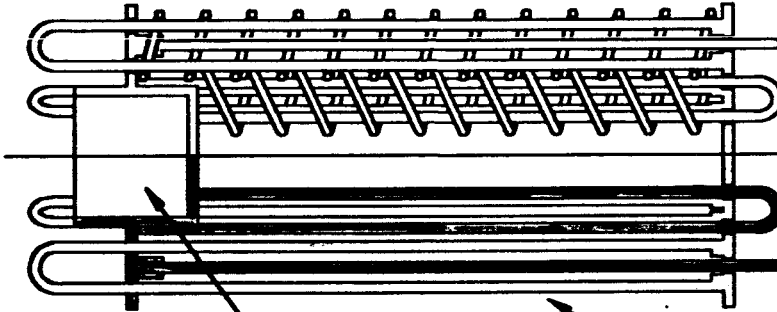
MARK MADLER AND JEFF WINGARD: Consulted Dr. Callen of the electrical engineering department and Reliance Electric in Cleveland, Ohio, about the use of a linear induction motor, but found it was currently impractical. Optimized a spring type launcher mechanism and consulted Dr. Meyers of the mechanical engineering department about high strength spring materials.

KEN NICHOLAS AND TERRY O'BANNON: Decided upon a velocity controller using the cranking motor as a damper; also researched a mass sensor, laser range and elevation finder and self-leveling sensors and position control motors.

DAVE CORBIN AND PHIL JOHNSON: Worked on calculations for the catcher structure and considered ideas to implement the catapult on the walker. Found that additional support upon launch will be needed. Phil also made this weeks CADAM drawings.

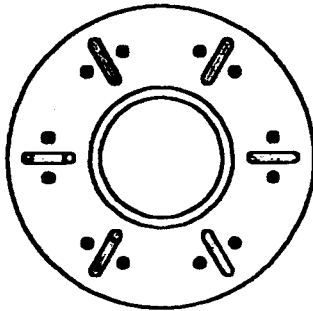


HALF SECTION
WITH SPRINGS



BAG HOLDER

GUIDE RODS

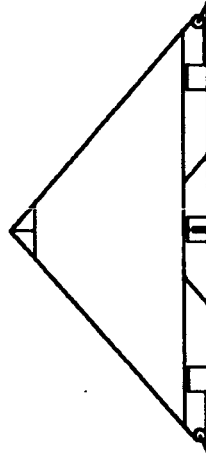
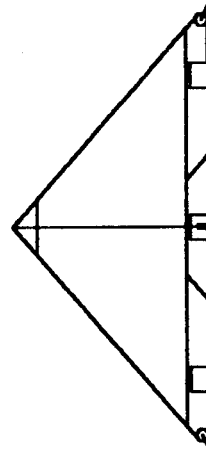
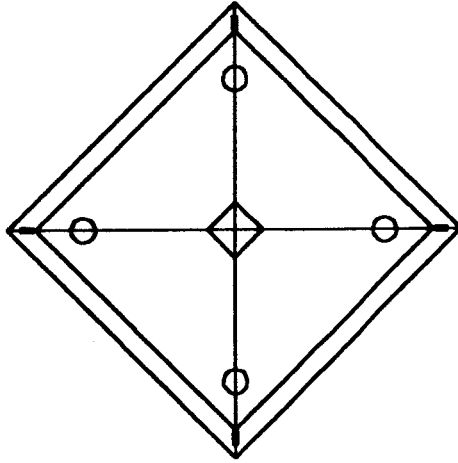


TOP VIEW

SIX SPRINGS:
EQUALLY SPACES
59 TURNS
DRAWBARS PREVENT
BUCKLING

GEORGIA TECH
COLLEGE OF ENGINEERING
TITLE: LAUNCHER SPRING
DESIGN: JEFF DATE 5/21
DRAFT: PHIL DATE 5/21
DRWG NO.

MULTI-DIRECTIONAL SANDBAG DECELERATOR



GEORGIA TECH
COLLEGE OF ENGINEERING

TITLE:

DESIGN:

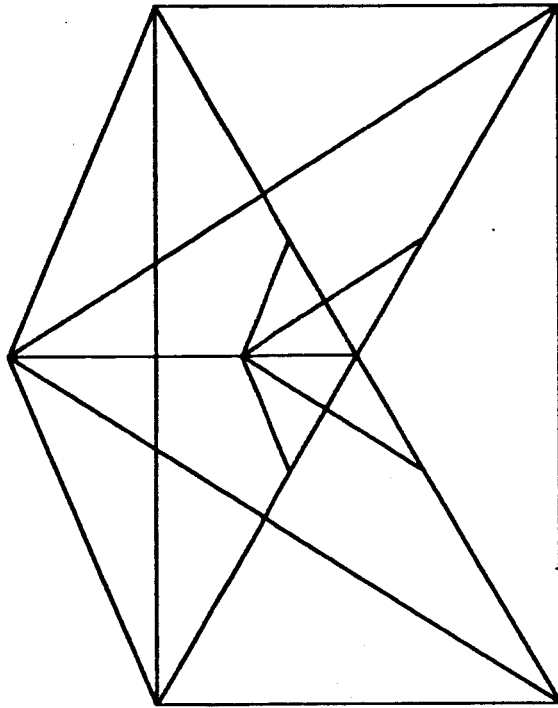
DATE

CHECK:

DATE

DRWG NO.

SCL



GEORGIA TECH			
COLLEGE OF ENGINEERING			
TITLE:			
DESIGN:	DATE		
CHECK:	DATE		
DRWG NO.	SCL		

APPENDIX F
PATENT DISCLOSURE

GEORGIA INSTITUTE OF TECHNOLOGY

INVENTION DISCLOSURE APPROVAL SHEET

The following questions should be answered by the laboratory or school director, as applicable. The questions are designed to verify the source of the invention and to obtain the viewpoint of other technically qualified scientists as to the uniqueness and efficiency of the invention. This approval MUST be completed before submission of the Invention Disclosure Form to the Office of Technology Transfer.

1. Title of InventionLUNAR SANDBAG TRANSPORTATION SYSTEM2. List of Inventor(s)DAVID CORBINMARK MADLERDON GRIFFINKEN NICHOLASPHIL JOHNSONTERRY O'BANNONDEAN O'DONALDJEFF WINGARD3. Ownership

In my opinion this invention is:

X A. Owned by the University in accordance with the Patent Policy.

_____ B. Was developed by the inventor(s) without use of University time, facilities or materials and is not related to the inventor's area of technical responsibility to the University. Belongs to the inventor(s).

4. Advisor approval for student submissions (if applicable):

Advisor_____
Date

Reviewed for University Ownership by laboratory or school director.

Name_____
Date_____
Title/Unit

GEORGIA INSTITUTE OF TECHNOLOGY
DISCLOSURE OF INVENTION

Submit this disclosure to the Technology Transfer Office (TTO) or contact the TTO for assistance. Disclosure must contain the following items: (1) title of invention, (2) a complete statement of invention and suggested scope, (3) results demonstrating the concept is valid, (4) variations and alternate forms of the invention, (5) a statement of the novel features of the invention and how these features distinguish your invention from the state of the art as known to you, (6) applications of technology, and (7) supporting information.

1. TitleTechnical Title: A LUNAR SANBAG TRANSPORTATION SYSTEMLayman's Title (34 Characters): LUNAR CATAPULT AND CATCHER

Inventor(s): (Correspondence, patent questions, etc. will be directed to the first named inventor)

A. Signature JH Wingard Revenue Share% 33 Date 6/4/87Printed Name In Full JEFFREY HARRY WINGARD Citizenship U.S.
First Middle LastHome Address 76 WELLES DR.City NEWINGTON County HARTFORD State CT Zip Code 06111Campus Unit/Mail Address BOX 30016 Campus Phone 355-2635B. Signature Mark R. Madler Revenue Share% 33 Date 6/4/87Printed Name In Full MARK ROBERT MADLER Citizenship U.S.
First Middle LastHome Address 9550 S. AIA, APT. 1406City JENSEN BEACH County MARTIN State FLORIDA Zip Code 33457Campus Unit/Mail Address BOX 36829 Campus Phone 873-5760C. Signature Donald K. Griffin Revenue Share% 33 Date 6/4/87Printed Name In Full DONALD KENNETH GRIFFIN Citizenship U.S.
First Middle LastHome Address 500 NORTHSIDE CIRCLECity ATLANTA County FULTON State GA Zip Code 30313Campus Unit/Mail Address BOX 35128 Campus Phone 351-2169

Disclosure No. _____

(Continuation Page)
DISCLOSURE OF INVENTION

2. Statement of Invention

Give a complete description of the invention. If necessary, use additional pages, drawings, diagrams, etc. Description may be by reference to a separate document (copy of a report, a preprint, grant application, or the like) attached hereto. If so, identify the document positively. The description should include the best mode that you presently contemplate for making (if the invention is an apparatus) or for carrying out (if the invention is a process) your invention.

ALL DETAILS AND DESCRIPTIONS OF THIS INVENTION ARE
PRESENTED IN THE ACCOMPANYING REPORT.

Inventor(s) Th. W. Inigard Date 6/4/87 Witness David Corbin Date 6/4/87
Mark Masler Date 6/4/87 Witness Ken A. Nichols Date 6-4-87
Donald K. Hoff Date 6/4/87 Witness [Signature] Date 6-4-87

(Continuation Page)
DISCLOSURE OF INVENTION3. Results demonstrating the concept is valid

Cite specific results to date. Indicate whether you have completed preliminary search studies, laboratory model or, prototype testing.

THE VALIDITY OF THE SYSTEM HAS BEEN RESEARCHED, CALCULATED AND THOROUGHLY DESCRIBED IN THE ATTACHED REPORT. IN ADDITION, A MODEL OF THE PROTOTYPE SYSTEM HAS BEEN BUILT.

4. Variations and alternative forms of the invention

State all of the alternate forms envisioned to be within the full scope of the Invention. List all potential applications and forms of the Invention, whether currently proven or not. (For example, chemical inventions should consider all derivatives, analogues, etc.) Be speculative in answering this section. Indicate what testing, if any, has been conducted on these alternate forms.

POTENTIAL APPLICATIONS

- ① LUNAR DEFENSE WEAPONS. ⑤ VIBRATIONAL DRILL
② SATELLITE LAUNCHERS ⑥ MOVING EQUIPMENT
③ WASTE DISPOSAL
④ HUMAN TRANSPORT

POTENTIAL FORMS

- ① DRAWBAR SPRINGS, LESS SPRINGS,
② MORE SPRINGS; COMPRESSION EXTENSION PAIRS.
③ LINEAR INDUCTION MOTORS.
④ CATCHER: PYRAMIDAL, ONE-SIDED,

Inventor(s) JH Wingard Date 6/4/87 Witness David Corbin Date 6/4/87

Mark Madoff Date 6/4/87 Witness Ken A. Mickel Date 6-4-87

Donald K. Huff Date 6/4/87 Witness Philip K. Huff Date 6-4-87

(Continuation Page)
DISCLOSURE OF INVENTION

5. Novel Features

a. Specify the novel features of your invention. How does the invention differ from present technology?

THE SYSTEM IS NOVEL SINCE IT IS A NEW APPROACH TO A NEW PROBLEM, MOVING SANDBAGS ON THE MOON. THE LAUNCHER IS NOVEL SINCE SPRINGS ARE USED TO DELIVER PROPULSION POWER. IT IS ALSO NOVEL SINCE IT WAS DESIGNED TO BE INTERFACED WITH THE LUNAR WALKER. THE CATCHER IS NOVEL SINCE IT IS MULTI-DIRECTIONAL AND RETURNS ENERGY TO THE PROJECTILE AS OPPOSED TO PLAIN ENERGY DISSIPATION.

b. What is the deficiency in the present technology which your invention improves upon, or the limitations it overcomes?

PRESENTLY, TRANSPORTING LUNAR SANDBAGS WOULD BE DONE BY TRUCKS ON THE MOON. THIS SYSTEM IS AN IMPROVEMENT FOR TWO REASONS. ONE IS THAT IT ELIMINATES ROLLING RESISTANCE, THEREBY IMPROVING EFFICIENCY. THE OTHER REASON IS THAT THE INVENTION IS AUTOMATED, ALSO IMPROVING EFFICIENCY AND ELIMINATING HUMAN LABOR.

c. Have you or an associate searched the patent and/or scientific literature with respect to this invention? Yes X No _____. If Yes indicate the literature found which you believe to be pertinent to your invention and enclose copies if available.

COPIES OF PERTINENT PATENTS ARE ENCLOSED IN THE APPENDIX OF THE ATTACHED REPORT.

d. Indicate any other art, either in the literature or technology used by others, of which you are aware that is pertinent to your invention and enclose copies if available. (Note: An inventor is under duty by law to disclose such art to the U.S. Patent and Trademark Office.)

ALL RESOURCES USED IN THIS INVENTION ARE LISTED IN THE BIBLIOGRAPHY AND ACKNOWLEDGMENT SECTIONS OF THE ATTACHED REPORT.

Inventor(s) JA Wingard Date 6/4/87 Witness David Corbin Date 6/4/87
Mark M. [unclear] Date 6/4/87 Witness Ken [unclear] Date 6-4-87
Don H. [unclear] Date 6/4/87 Witness [unclear] Date 6-4-87

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DISCLOSURE OF INVENTION
SUPPORTING INFORMATION

6. Application of the technology

List all products you envision resulting from this invention, and whether these products could be developed in the near term (less than 2 years) or long term (more than 2 years).

EARTH APPLICATIONS OF THE SYSTEM ARE NOT PROBABLE, SINCE ONE OF ITS PURPOSES IS TO TAKE ADVANTAGE OF THE LUNAR LACK OF ATMOSPHERE, WHICH IS NOT TRUE ON EARTH. THEREFORE, THIS LIMITS APPLICATIONS TO SPACE, WHICH MEANS ANY PRODUCTS WILL BE LONG TERM.

POSSIBLE PRODUCTS:

- ① EQUIPMENT MOVING AAA SYSTEMS.— SUPPLIES AND TOOLS WILL BE SENT FROM THE MODULE TO THE WORK SITES.
- ② TERRESTRIAL ELEVATOR — WORKERS (ASTRONAUTS) MAY BE TRANSPORTED TO HILL AND CRATER TOPS FROM DOWN BELOW WITH MINIMAL EFFORT, MAKING NEW HARD TO REACH LUNAR SITES ACCESSIBLE.
- ③ SATELLITE LAUNCHER.

Inventor(s) TH Wingard Date 6/4/87 Witness David Corbin Date 6/4/87
Mark Mapple Date 6/4/87 Witness Ken A. Wright Date 6-4-87
Donald K. Giff Date 6/4/87 Witness Phil [unclear] Date 6-4-87

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DISCLOSURE OF INVENTION
SUPPORTING INFORMATION

1. As there publications-theses, reports, preprints, reprints, etc. pertaining to the invention? Please list with publication dates. Include manuscripts for publications (submitted or not), news releases, feature articles and items from internal publications.

THE ONLY PUBLICATION OF THIS INVENTION IS THE REPORT ATTACHED TO THIS DISCLOSURE. THE DATE OF PUBLICATION IS 6/5/87.

2. What was the date the invention was first conceived? 4/13/87 Is this date documented? YES Where? LAB NOTEBOOKS Are laboratory records and data available? Give reference numbers and physical location, but do not enclose.

THE RECORDS ARE AVAILABLE IN A LAB NOTEBOOK KEPT THROUGHOUT THE PROJECT BY MARK MADLER.

3. A literature search should be done by the inventor to determine publications relevant to the Invention. Please list and any related patents known to you. RELATED PATENTS ARE IN THE REPORT APPENDIX. HOWEVER, THE CATCHER IS BASED ON A MANUFACTURED AIRPLANE RESISTOR BY ALL AMERICAN ENGINEERING.

4. Date, place, and circumstances of any disclosure. If disclosed to specific individuals, give names and dates. WEEKLY PROGRESS DISCLOSED TO MR. J.W. BRAZELL. OVERALL DISCLOSURE TO ME 4182 DESIGN STUDENTS 6/5/87 AS A PRESENTATION.

5. Was the work that led to the invention sponsored? If yes, check the appropriate blank(s). Government agency X, industrial company _____ university _____ other _____.

Sponsor

NASA

Project No.

6. What firms do you think may be, or are interested in the invention. Why? Name companies and specific persons if possible.

NASA FUNDED THE PROJECT IN ORDER TO ESTABLISH A DATA BASE FOR THEIR SPACE MODULE PROGRAM, PROJECTED TO BEGIN IN THE 1990'S.

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DISCLOSURE OF INVENTION
SUPPORTING INFORMATION

7. Being for the moment the Devil's Advocate, what do you see the greatest obstacle to the adoption of your invention?

THE NOVELTY OF IT. THE COMPONENTS THEMSELVES ARE NOT NOVEL; HOWEVER, THE OVERALL SYSTEM AND APPLICATION OF THESE COMPONENTS IS UNIQUE.

8. Alternate technology and competition

a. Describe alternate technologies of which you are aware that accomplish the purpose of the invention. PURPOSE - MOVE SANDBAGS

① A TRUCK

② CONVEYER BELT

b. List the companies and their products currently on the market which make use of these alternate technologies.

CATCHER - ALL AMERICAN ENGINEERING - AIRPLANE RESISTOR.

c. List any research groups currently engaged in research and development in this area. NONE TO OUR KNOWLEDGE.

9. Future research plans

a. What additional research is needed to complete development and testing of the invention? What are the time frames and estimated budget needed for completion of each step? FURTHER RESEARCH IS NECESSARY TO SELECT THE CORRECT MOTORS AND POSSIBLY ~~DEER~~ OPTIMIZE THE SIZE AND WEIGHT OF THE CATCHER. A 2 YEAR, \$1 MILLION BUDGET IS PREDICTED TO COMPLETE THIS RESEARCH, AS WELL AS CONSIDER THE LINEAR INDUCTION MOTOR ALTERNATIVE.

b. Is this research presently being undertaken? Yes _____ No ☒ Actively pursued? Yes ☒ No _____ If yes, under whose sponsorship? NASA
If no, should corporate sponsorship be pursued? Yes _____ No _____.

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DISCLOSURE OF INVENTION
SUPPORTING INFORMATION

10. Was this invention conceived or reduced to practice in the course of an extramurally sponsored project yes X no ____.

a. If yes, has sponsor been notified of this invention yes X no ____.

b. If yes, please provide Georgia Tech project number(s) so that sponsor's rights to this invention may be determined. _____

11. Attach, sign and date additional sheets if necessary. Enclose sketches, drawings, photographs and other materials that help illustrate the description. (Rough artwork, flow sheets, Polaroid photographs and penciled graphs are satisfactory as long as they tell a clear and understandable story.)